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Luigi Palazzo
1861-1933

TERRESTRIAL-MAGNETIC ACTIVITY IN THE YEARS 1931 AND 1932

By J. Bartels

For a continuation of the series of the u-measure of terrestrial-magnetic activity[1] daily means of the horizontal intensity in the years 1931 and 1932 were used for four observatories—De Bilt, Honolulu, San Juan, and Tucson (the last mentioned only for January 1931 to August 1932). The data for De Bilt, 1932, were published in November 1933, while the other data were kindly supplied, in advance of publication, by the Director of the United States Coast and Geodetic Survey. The conversion-factors k, for Honolulu and Tucson, are 1.14 and 1.44, as formerly; for San Juan, k was chosen as 1.24; for De Bilt $k = 1.75$ was determined by direct comparison with Seddin for the seven years, 1921 to 1927.

A short *definition of u* may be repeated as the average change, taken without regard to sign, measured in the unit 0.0001 c.g.s. $= 10\gamma$, of the daily means of horizontal intensity on the magnetic equator of the Earth. The monthly means of u_1 are derived from those of u: For values of u from 0.0 to 0.6, $u_1 = (100\ u - 30)$; for higher values, u_1 increases less rapidly, approaching asymptotically the limiting value 140. The quantity u_1 has been introduced in order to obtain a measure of activity which has a frequency-distribution similar to that of the relative sunspot-numbers, and therefore is more suitable for research on correlations between terrestrial-magnetic activity and solar activity.

Up to the end of the year 1930, terrestrial-magnetic activity remained high; it is only since 1931 that u_1 follows R in the decline toward the sunspot-minimum. In the former paper (p. 35), u_1 as a function of R was represented by a curved regression-line; the deviation $\triangle u_1 = (u_1 - u'_1)$ of the observed u_1 from the value u'_1, corresponding to R, as read from

[1] J. Bartels, Terr. Mag., **37**, 1 (1932).

TABLE 1—*Monthly means, u-measure and u₁-measure, 1931 and 1932*

[Continuing tables for 1872 to 1930 in *Terrestrial Magnetism*, **37**, of u-measure on page 9 (that table for u is, by misprint, headed erroneously as u_1), and of u_1-measure on page 15]

Meas-ure	Year	Month												Mean
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
u	1931	0.58	0.71	0.63	0.71	0.75	0.85	0.56	0.67	0.88	1.06	0.80	0.51	0.73
	1932	0.54	0.59	0.88	0.68	0.94	0.65	0.63	0.67	0.71	0.81	0.59	0.73	0.70
u_1	1931	28	41	33	41	44	53	26	37	56	70	49	21	42
	1932	24	29	56	38	61	35	33	37	41	50	29	42	40

TABLE 2—*Annual means of u-measure, u_1-measure, relative sunspot-numbers R, and international magnetic character-figures C*

[The means entered against 1928.0 are for the 12 months July 1927 to June 1928, those against 1928.5 are for the 12 months January to December 1928, etc.]

Year	u	u_1	R	$\triangle u_1$	C	$\triangle C$
1928.0	0.89	54	71	−13	0.61	−0.02
28.5	0.99	61	78	−10	0.63	−0.03
29.0	1.14	72	67	+ 7	0.66	−0.04
29.5	1.05	67	65	+ 3	0.67	−0.01
30.0	0.96	62	56	+ 2	0.80	+0.14
30.5	1.00	63	36	+ 9	0.83	+0.16
31.0	0.89	54	28	+ 6	0.67	+0.04
31.5	0.73	42	21	− 2	0.66	+0.08
32.0	0.73	42	15	+ 3	0.76	+0.18
32.5	0.70	40	11	+ 6	0.70	+0.12
33.0	. . . .	. .	9	. . . .	. . . .	. . . . . .

this regression-line, is given in Table 2. The positive values for $\triangle u_1$ conform to the lag of terrestrial-magnetic activity behind solar activity, found for previous sunspot-cycles.

The five months, August to December 1932, are of special interest as the beginning of the Second International Polar Year. Their average for u_1 is· 40, indicating quiet conditions. The 12 months of the first Polar Year, 1882 to 1883, had an average $u_1 = 64$, with the highly disturbed months October and November 1882 ($u_1 = 108$ and 136). No u_1-values can as yet be given for 1933; but judging from the reports on "Principal magnetic storms" in this JOURNAL, the second part of this Polar Year has been quiet as well, the only magnetic storm occurring April 30 to May 2, 1933, and being of moderate intensity but with a definite sudden commencement. The relative sunspot-number for the Second Polar Year (August 1932 to July 1933) is already available, namely $R = 8$; that for the First Polar Year was $R = 59$.

The international character-figures (C) do not reflect the obvious decrease in magnetic activity. This is due to a break in the homogeneity in the series for C, beginning with 1930, and already indicated in the former paper (p. 33). By means of a linear regression-formula ($C' = 0.00392\,u_1 + 0.421$), values C' are coordinated to u_1; the differences $\triangle C = (C - C')$ between the observed values C and the computed values C' are given in Table 2. $\triangle C$ is positive throughout the last three years. The character-estimation is therefore systematically higher than the standard established in the years 1906 to 1929.

Because of the usefulness of the character-figures in many respects, it is of interest to trace this shift in detail. The average of C for a year is the result of the frequency of days with $C = 0.0$, 0.1, 0.2, etc., up to 2.0. Identical changes in the average for the year therefore can be brought about in many ways by various changes in this frequency-distribution. This frequency-distribution was determined for the years, 1930 to 1932 by simple counting. For comparison, the years 1909 to 1911 were chosen, because they have exactly the same average $u_1 = 48$ as 1930 to 1932 and represent similar conditions, being at the end of a sunspot-cycle. The average C for 1909 to 1911 was 0.66, for 1930 to 1932 was 0.73; $\triangle C$, for the same intervals, was +0.05 and +0.12, respectively. In spite of this small difference in the average, the frequency-distributions (Table 3) show characteristic differences, which will now be discussed.

TABLE 3—*Frequency (number of days in 3 years) of international magnetic character-figures C*

C	1909 to 1911	1930 to 1932	Change	C	1909 to 1911	1930 to 1932	Change
0.0	45	78	+33	. . .	. .	. .	. . . .
0.1	122	77	−45	1.1	73	82	+ 9
0.2	92	91	− 1	1.2	39	60	+21
0.3	85	69	−16	1.3	23	45	+22
0.4	75	71	− 4	1.4	19	40	+21
0.5	57	57	0	1.5	13	31	+18
0.6	63	61	− 2	1.6	14	20	+ 6
0.7	85	56	−29	1.7	9	22	+13
0.8	73	84	+11	1.8	10	9	− 1
0.9	111	70	−41	1.9	4	7	+ 3
1.0	80	64	−16	2.0	3	2	− 1

The higher frequency of the figure 0.0 in the years 1930 to 1932 is counterbalanced by a lower frequency of the figure 0.1. Now it is a common experience that 0.0 and 0.1 denote practically the same degree of very low activity; it therefore is reassuring to note that the frequencies of 0.0 and 0.1, taken together, are 167 and 155 for 1909 to 1911 and 1930 to 1932; that is, practically the same. The higher percentage of 0.0-days in 1930 to 1932 is an indication of greater unanimity of the collaborating observatories, some estimators, who tended to report 1 for a perfectly quiet day, having improved since 1911. From $C = 0.2$ to 0.5, the total frequencies are 309 and 288 for 1909 to 1911 and 1930 to 1932; from 0.6 to 1.0, 412 and 335; from 1.1 to 1.7, 190 and 300 (in particular, from 1.4 to 1.7, 55 and 113, that is a doubling of frequency); from 1.8 to 2.0, 17 and 18. The *characteristic difference* between the triennial periods is the *higher frequency of character-figures 1.1 to 1.7 in the years 1930 to 1932.* It is obvious that a number of observatories must have used the character 2 more freely.

For illustration, imagine each of the 1095 days of the years 1909 to 1911 represented by a small rectangular area, and imagine these areas put together in a strip in the order of increasing magnetic activity. The assignment of the international character-figures C can then be conceived as a division of this strip into a scale with 21 parts, the first representing the days with $C = 0.0$, the last those with $C = 2.0$. The same can be done for the 1096 days of the years 1930 to 1932. The two scales can easily be constructed, the length of each successive division being proportional to the frequencies given in Table 3. They are reproduced in Figure 1. The two scales should be approximately equal, if C should
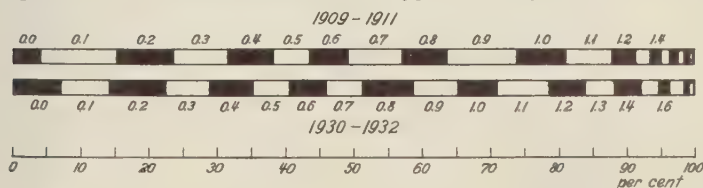
FIG. 1—Frequency of international magnetic character-figures C

correspond to the more objective measure u_1. From $C = 0.0$ to 0.5 (that is, for about 40 per cent of all the days), there is no serious discrepancy, but to the same degree of activity $C = 0.8$ would have been assigned

in the first period, $C = 0.9$ in the second, etc. A degree of activity indicated by $C = 1.1$ to 1.4 in the first period would correspond to $C = 1.3$ to 1.6 in the second.

Looking over these results, it is clear that the scale of character-estimation has changed, so that the monthly and annual averages of terrestrial-magnetic activity cannot be judged from C, but only from u or u_1. Still, the value C for each single day does not differ so much, if judged according to the standard of 1910 or 1930. Up to 0.6, the difference would be less than 0.1, and only upward of $C = 1.1$ does the difference reach 0.2. Some slight correction of C with the help of diagrams like Figure 1 would seem sufficient in most cases to reduce C to a common standard. But certainly a new revision of the norms of estimation now in use at the observatories should not be recommended, because this would mean another break in the homogeneity.

In a former paper[1], the relations between various measures of terrestrial-magnetic activity and solar activity have been discussed. Since then, W. Brunner has published a fine series of a measure of solar activity, namely, the monthly means of the profile areas of the *solar limb-prominence* in the years 1910 to 1932[2]; for obvious physical reasons, this measure would seem to promise higher correlations with terrestrial-magnetic activity. In fact, Brunner, in a preliminary calculation[3] based on the years 1923 to 1929, has found a superiority of the prominences P over the sunspot-numbers R inasmuch as the correlation between u and P is higher than between u and R. The writer's calculated averages of u_1, R, and P for all quarters (three-monthly intervals), 1910 to 1932, and their correlation-coefficients are given in Table 4.

TABLE 4—*Correlation-coefficients between quarterly means of terrestrial-magnetic activity u_1, relative sunspot-numbers R, and areas of solar limb-prominences P, 1910 to 1932*

Group	Number of quarters	Correlation-coefficient between		
		u_1 and P	u_1 and R	P and R
All quarters........	92	0.711	0.739	0.840
Few obs'ns of P....	33	0.625	0.720	0.805
Many obs'ns of P..	59	0.765	0.754	0.859

Judged from the result for all quarters, the correlation between u_1 and P is certainly not closer than that between u_1 and R. But in order to give P a fair test, the quarters were divided into two groups—one with few observations of P, less than 33 per quarter, and the other with 33 or more observations per quarter. This was possible because Brunner's table gives also the number of observations per month. The correlations, given in the second and third lines of Table 4, speak for themselves; the advantage of P over R in the quarters with many observations is too slight to mark a real superiority. The third column shows the typical high correlation between various measures of solar activity and how it is affected by the frequency of observations of P.

[1] Astr. Mitt. Zürich, **130**, 217 (1933).
[2] Int. Astr. Union, Character-figures of solar phenomena 1923-1928, Zürich 1932, p. VII.

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A POSSIBLE TEST FOR THEORIES OF MAGNETIC DIURNAL-VARIATIONS AND OF MAGNETIC STORMS

By A. G. McNish

Three plausible theories[1] have been offered to explain the magnetic diurnal-variations—the atmospheric-dynamo theory as suggested by Balfour Stewart and extended by Schuster and Chapman, the diamagnetic theory as outlined by Gunn, and the drift-current theory as developed by Chapman as a natural consequence of the conditions necessary to the diamagnetic theory. Regardless of the spontaneous merits of these theories, much information concerning their respective probabilities should be derivable from the study of radio-wave reflections from the ionosphere.

The atmospheric-dynamo theory ascribes the magnetic variations to currents flowing in the ionosphere induced by the tidal motions of the air. Gunn[2] has questioned the possibility of such currents because in the region of long free-paths the average motion of the ions will be in the direction at right-angles to the magnetic and electric fields present rather than in the direction of the induced electromotive-force. This objection is in part unwarranted because in middle and high latitudes the ions, carried by the moving air-masses, will have their motions diverted by the Earth's magnetic field exactly as if the induced electromotive-forces, to which they presumably cannot respond, were acting upon them. However, in equatorial regions where the vertical component of the Earth's magnetic field is practically zero, this condition does not exist and the current-systems cannot close in the regions of long free-paths. An accumulation of charge would result, positive to the west and negative to the east of the noon meridian, and, in spite of the electrostatic field thus set up, no current would flow unless the mean free-path of the ions is short as compared with the radii of curvature about the magnetic lines of force due to their gas-kinetic velocities. From our facts and surmises concerning the ionosphere it follows that, although the diurnal-variation currents in middle and high latitudes may have their seat in the richly ionized portion of the upper ionosphere, the closing of the current-systems must occur much nearer the Earth's surface where the mean free-path is short—presumably in the E-layer.

The magnetic force at the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington is on the average over 0.001 gauss greater around noon than in the morning and in the evening[3], while frequently the noon excess on quiet days is even twice this amount. According to the presumptions stated above, the magnetic force above the E-layer should be lower around noon by 0.001 gauss because it is above the current-sheet. Detection of this decrease above the E-layer of the ionosphere would furnish a convincing argument in favor of the atmospheric-dynamo theory.

[1] S. Chapman, Proc. R. Soc., **122**, 369-386 (1929).

[2] Phys. Rev., **32**, 133 (1928).

[3] H. F. Johnston and A. G. McNish, C. R., Cong. Intern. Electricité, Paris, **12**, 41-52 (1932).

While the E-layer in equatorial regions is much more favorable to the operation of the atmospheric-dynamo principle, the diamagnetic and drift-current theories require rich ionization in the upper part of the ionosphere where the mean free-path is quite long. A decrease around noon in the magnetic force, on the basis of either of these latter theories, would not be expected in the lower portions of the F-region, although deep in the F_2-layer the diamagnetic theory would call for a decrease in the magnetic force.

Numerous investigators[4] have shown that, due to magneto-ionic double refraction, radio waves are returned from the same height, and consequently from regions of equal ionic density, in the ionosphere at two different frequencies, the frequency-separation of which is a funtion of the magnetic field at the height at which reflection takes place. Although at present uncertainties attend the determination of the magnetic force in this way, due to our inability to translate virtual heights into actual heights for lack of detailed knowledge of group-retardations of the two components, of dissipation, and of other phenomena, nevertheless it may be possible ultimately to trace the variations in magnetic force at a given height throughout the day by variations in the frequency-separation of the two components. If this variation can be determined with the requisite accuracy—about 0.001 gauss—the seat of the cause of the diurnal magnetic-variations may be revealed. The unusual magnitude of the magnetic variations at the Huancayo Magnetic Observatory would recommend that place for such an investigation. Valuable indications of the field-changes during magnetic storms might likewise be obtained.

Radio data obtained so far, essentially of a pioneering nature, have not been suited to a highly specialized investigation of this sort, nor has the theory of reflections been extended sufficiently to account for factors which must be considered in such precise measurements. The solution of the problem which has been outlined, if its solution is possible, would constitute one of the great contributions ionosphere-investigation has to offer to our understanding of terrestrial magnetism.

[4] G. Breit, Proc. Inst. Radio Eng., **15**, 709-723 (1927); E. V. Appleton, J. Inst. Electr. Eng., **71**, 642-665 (1932); L. V. Berkner and H. W. Wells, Report of ionosphere-investigations at the Huancayo Magnetic Observatory (not yet published); E. V. Appleton and G. Builder, Proc. Phys. Soc., **45**, 208-220 (1933); S. S. Kirby, L. V. Berkner, and D. M. Stuart, Bur. Stan. J. Res., **12**, 15-51 (1934).

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THE ATMOSPHERIC POTENTIAL-GRADIENT AT BOULDER, COLORADO

By James W. Broxon and Louis Strait

Abstract—Potential-gradient records were made at Boulder for a period of several months. The diurnal variation on clear and undisturbed days was of the double-maximum type with the usually principal maximum at about 9^h, and a second maximum at about 18^h, local time. Not only the daily mean gradient, but also all the Fourier harmonic amplitudes (with the exception of the third, which remained constant) were greatest during late winter and least during late summer. The fundamental phase-constant showed the presence of Mauchly's universal-time "wave" of 24-hour period. The seasonal variations of this phase-constant also resembled those at most stations. The local-time phase-constant of the second harmonic, $\phi_2 = 190°$, was about that found by Mauchly for many land stations. The 6-hour harmonic of the general mean curve also resembled that at sea and some land stations, amounting to 6 per cent of the daily mean, with zero phase-angle at local midnight.

Introduction

In view of the scarcity of atmospheric-electric data from far-inland, high-altitude stations in North America, it was considered that a somewhat extended series of observations of the local atmospheric potential-gradient would be of interest. The University of Colorado campus is located at Boulder, a small, non-industrial city, distant twenty miles from Denver, the only industrial city in the neighborhood. Boulder occupies a rather unique marginal position on the plains directly at the base of the Front Range of the Rocky Mountains. The location of the campus relative to the mountains is shown clearly by the topographic map, Figure 1, and the aerial photograph, Figure 2. The nearest foothills subtend vertical angles of the order of $10°$ westward from the campus.

At the suggestion of the senior author, J. F. Mackell[1] made some preliminary observations of the potential gradient here during the late summer of 1927. He used a radioactive collector and a gold-leaf electroscope, observations being made visually at about five-minute intervals during the daylight hours from 6 to 20, mountain standard time (M. S. T.), for a period of five weeks. (All references to time are to mountain standard time, which is that of the meridian $105°$ west, and are reckoned from 0^h as midnight through 24^h.) He distinguished a principal maximum at about 16^h and a smaller maximum at about 9^h on clear days. The roughly estimated range of his clear-day average curve during the designated hours was about 90 to 130 volts per meter, positive. Once during a brief thunderstorm he found the gradient reversed for a period of about an hour and attained negative values exceeding 1400 volts per meter, the negative values being preceded and succeeded by rather high positive values.

Equipment and location

In the late summer of 1930 the writers set up equipment designed to supply continuous photographic records of the potential gradient. A radioactive source in the form of a bottle stopper with a prolongation which had been submerged in a radioactive solution for a long period was tied to the end of a brass rod and protected from rain by a metal cone

[1] J. F. Mackell, Proc. Ind. Acad. Sci., **37**, 179 (1927-8).
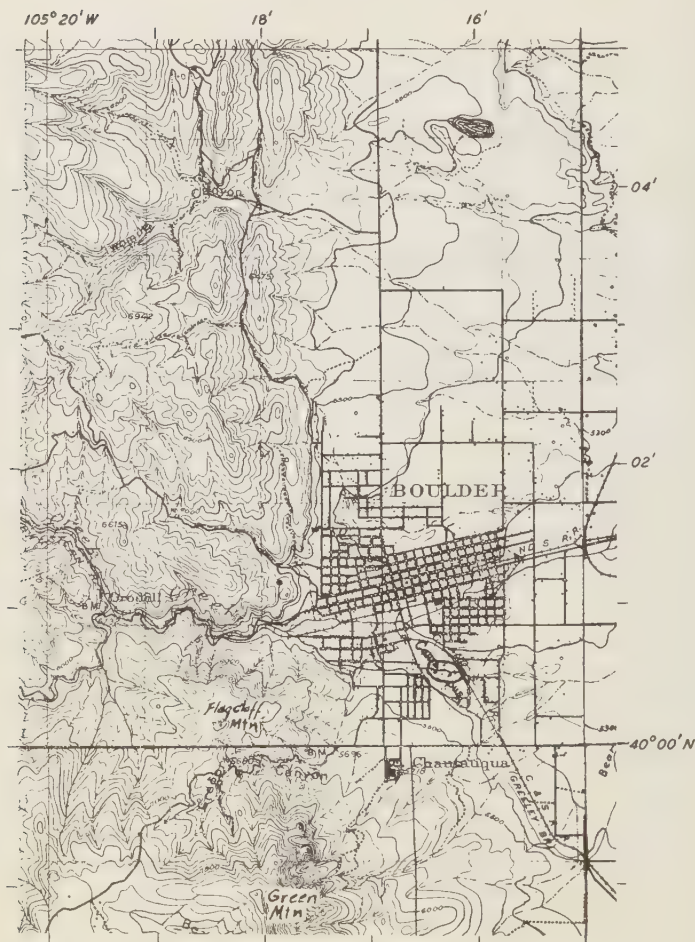
Fig. 1—Topographic map of Boulder and vicinity

fastened above it. This was projected about 5 feet outside the outer surface of the south wall of the east wing of the Chemistry Building, at a point about 39 feet above the surface of the Earth which was relatively free from shrubbery in the neighborhood. In this position, the collector was about 5444 feet above sea-level at a position about 105° 16′ west and 40° north. The rod was insulated by two hard-rubber insulators inside the attic of the building, in which was located the electrometer and recorder. A wire connected the rod with the needle of a Dolezalek quadrant-electrometer mounted upon an iron shelf fastened directly to the stone wall of the building. The case of the electrometer and
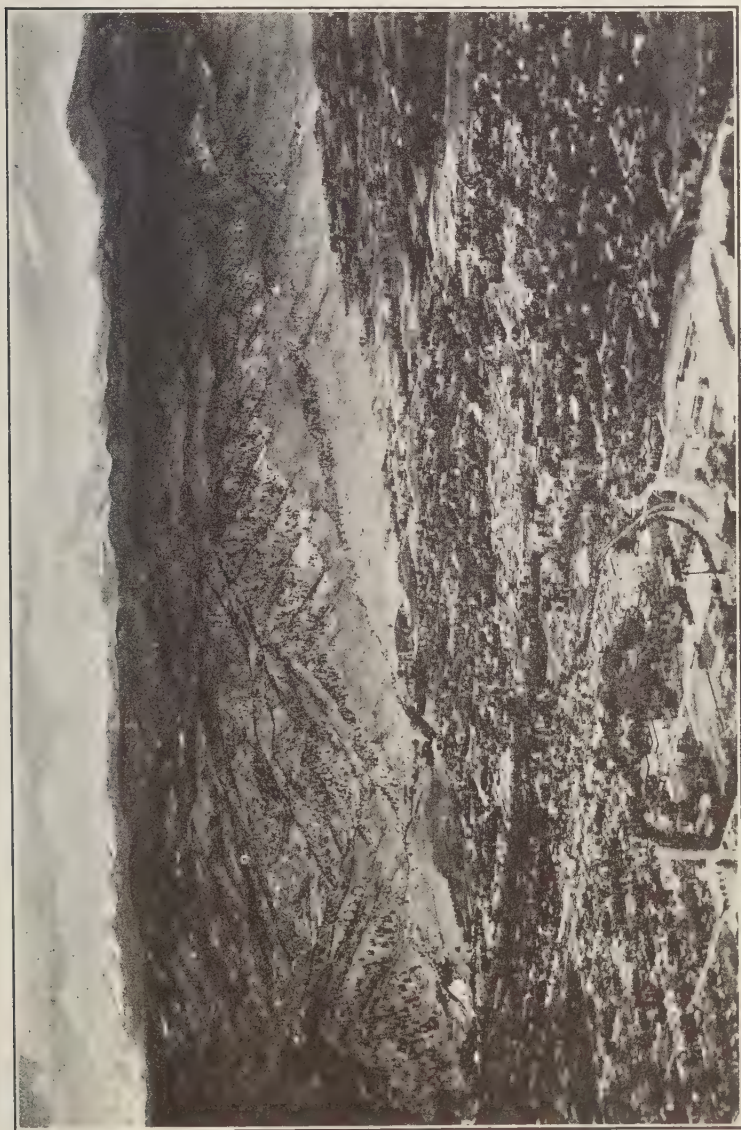
Fig. 2.—Aerial photograph of Boulder and vicinity

one pair of quadrants were earthed by a wire soldered to the water pipes of the laboratory, and a constant potential-difference between the quadrants was maintained by an insulated dry-cell. The potential of the collector-system was recorded by means of a beam of light reflected from the electrometer-mirror onto photographic paper, 20 cm by 50 cm, attached to the drum of an Askania-Werke recorder which rotated once in 25 hours. Light was excluded from the attic by a baffle-system of black papers which nowhere connected the insulated system with an external object.

With this arrangement, the shortest leakage path provided by the insulators supporting the collector-rod was about 1 inch and the conventional electrometer-needle insulator offered a very short path for surface-leakage inside the instrument. Therefore, in spite of the facts that all insulation was indoors, that the climate is relatively dry, and that the collector-system was found to attain potentials of the order of 200 volts within two-minute intervals after insulating from earth, it was feared that the insulation might not be adequate. Consequently, more thorough insulation was designed and installed February 6, 1931. This supported the collector-rod rigidly from the wall by means of four hard-rubber rods each 1 inch in diameter and 15 inches long. As shown in

Fig. 3—Photograph of recording-equipment

Figure 3, to escape over these insulators charges must have leaked nearly their entire length. Also, the rods were readily accessible for frequent scraping and cleaning. Moreover, the new ebonite-insulator for the electrometer-needle, shown in longitudinal section in Figure 4, offered much greater resistance to surface-leakage at that point. The dust-cap shown aided materially in keeping the external surfaces of this insulator clean.

Calibration of the apparatus

The voltage-calibration of the apparatus was effected by maintaining the needle potential at a constant known value relative to earth for a few minutes, thus producing a straight line on the recording paper, then changing to others, thus obtaining a series of lines on the paper corresponding to various known potentials between zero and values near the maximum which could be recorded. This procedure was repeated from time to time. In particular, as the season advanced it was found that high off-scale values necessitated decreased sensitivity of the instrument. Accordingly, the gold needle-suspension was shortened more than once, necessitating recalibration in each instance. In all, seven voltage-calibrations of the apparatus were made. The zero-potential position was found to shift somewhat with time. Consequently, the zero-position was checked frequently. After the first few months, it was customary

Fig. 4—Longitudinal section of electrometer-needle insulation

to earth the collector-rod for a few minutes at the beginning of each new daily record. It was found that the zero-shifts did not appreciably affect the calibration-curve, the entire curve being shifted by an amount equal to the zero-shift.

To convert the recorded collector-voltages to vertical potential-gradient values in volts per meter, a reduction-factor was determined by a Simpson and Wright[2] horizontal-wire experiment. Adjacent to the south side of the building in which the recording equipment was mounted was a considerable smooth, horizontal area with very short turf and free from shrubbery, an abandoned football-field. Near the center of this area a wire was stretched horizontally, with a central collector consisting of freshly crushed old radon tubes held on the surface of a small, horizontal, 2-cm by 5-cm copper plate by a film of water-glass. The wire was suspended from small iron posts 113.5 cm high separated by a distance of 65 feet. The wire was attached to the post at each end by a freshly molded sulphur-insulator, a glass-insulator, and a rubber-insulator in series. The shortest surface-leakage paths over the insulation were about 1.5 cm for the sulphur-, 5 cm for the glass-, and 30 cm for the rubber-insulators. The turnbuckle-and-insulator system at the post nearer the electrometer occupied a distance of 1 meter, and the insulator-system at the other end a distance of 80 cm. The insulator-systems were attached to the posts at points about 112.5 cm above the surface of the Earth, and the radioactive collector, attached to the insulated wire at a point 9.7 meters from the post nearer the electrometer, was just one

[2]G. C. Simpson and C. S. Wright, Proc. Roy. Soc., A85, 175 (1911).

Table 1--Atmospheric potential-gradient in volts per meter

Date	Mountain standard time (105° west meridian)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1930																								
Sep. 11																	57	59	37	31	58	30	29	31	28
12	25	47	31	34	44	60	64	85	85	64	45	27	40	66	85	76	85	69	85	53	54	28	31	27
13	30	25	28	25	31	47	85	63	64	59	41	48	37	28	28								49	58
14	49	51	43	34	43	65	79	68	83	83	61	68												
15													63	53	53	69	42	40	37	34	29	23	37	
16	34	33	30	27	30	46	80	61	79	80	79	46	41	59	54	58	85	83	50	52	59	41	32	31
27																							18	25
28	24	18	18	16	14	20	69	67	79	40	15	60	54	13	31	25	76	54	25	17	16	16		
Means	32	35	30	27	32	48	75	69	78	65	48	50	38	46	50	54	75	57	46	43	31	29	31	31
Nov. 8																						25	25	34
9	22	30	62	37	27	34	51	138	54	55	43	49	56	54	11	35	54	30	30	25	26	25	—	25
10	34	52	26	25	25	36	49	42	40	32	40	—	—	—	52	22	89	115	94	46	37	37	33	32
11	31	26	28	25	26	34	64	105	—	81	106	72	67	95	55	49	81	78	50	43	56	54	50	99
12	86	112	119	*	45	82	106	96	117	84	40	8	0	13	20	21	27	134	43	35	21			
20																					33	58	43	30
21	17	8	25	17	43	57	57	59	45	3	0	51	42	49	62	61	107	6	3					
25																							124	86
26	55	84	52	71	58	102	94	128	157	111	128	30	43	26	49	77	36	30	20	25				
28																				30	25	85	85	54
29	46	36	54	58	21	17	32	47	78	*	122	81	81	80	99	131	135	145	108	98	58	37	51	95
30	66	68	90	95	117	128	129	96	156	115											122	136	54	54
Means	46	52	57	47	45	59	73	89	92	69	68	49	45	53	47	57	76	77	50	43	45	55	58	57
Dec. 1	51	57	48	41	83	95	132	196	128	151	143	164	154	117	82	155	168	151	122	78	74	89	81	37
2	62	49	58	56	32	85	115	115	164	166	152	77	122	122	95	104	90	123	115	49	56	30	31	17
3	17	14	17	18	8	24	51	95	157	140	104	86	106	81	73	96	125	96	71	105	129	109	143	117
4	117	108	128	81	119	143	187	180	151	157	164	106	94	122	54	62	59	165	72	83	81	59	62	30
5	50	36	51	67	94	115	166	147	111	162	151	153	98	86	63	90	143	67	66	90	89	90	108	128
6	131	95																						
7																			36	89	43	38	46	26
8	38	68	23	21	36	117	138	153	172	160	154	108	151	109	49	81	82	56	24	22	21	49	81	64
9	81	81	26	17	102	94	115	129	187	164	188	122	117	70	49	102	106	54	30	24	11	4	38	43
10	18	20	*	49	52	94	81	30	132	4	54	77	84	77	43	50	43	47	78	—	—	—	77	71
11	62	58	47	102	43	54	75	104	151	160	111	117	90	85	149	71	43	151	85	58				
12																							104	75
13	64	54	43	140	64	64	122	107	143	157	102	110	76	76	64	58	68	108	24	48				
Means	61	56	47	57	63	89	118	126	148	142	132	112	105	94	72	83	93	101	68	64	61	59	77	61
1931																								
Jan. 2																					51	34	18	60
3	25	26	26	0	43	13	2	62	117	156	119	66	48	29	48	51	17	19	38	47	55	43	45	18
4	13	49	19	38	64	94	81	89	104	117	125	*	26	17	9	9	0	9	15	0	28			
5																					64	77	64	
6	66	36	45	32	55	51	100	55	98	164	98	162	174	94	115	151	130	115	65	7	2			
8																				52	83	60	50	40
9	21	49	9	9	8	12	16	21	81	157	128	89	104	94	85	68	98	32	4	13	13	13	21	30
10	28	17	0	21	15	9	2	26	157	165	166	130	132	115	114	111	160	79	17					
12																				102	110	115	136	59
13	100	118	89	87	57	82	83	0	0	5	36	62	83	79	94	60	79	121	68	54	80	70	60	89
14	144	149	99	*	158	80	158	40	*	140	155	86	152	158	160	118	191	158	147					
16																				10	12	28	54	8
16	3	0	0	0	0	18	72	184	134	107	95	81	75	77	82	91	119	40	55	100	108	77	167	
17	128	109	31	74	105	87	9	28	32	57	104	123	83	98	32	61	79	78	64	77	21	—	—	25
18	117	155	81	98	50	79	101	152	*	128	81	39	36	26	20	13	119	19	62	43				
Means	64	71	40	40	55	51	57	55	97	119	112	98	92	79	75	72	96	75	52	40	50	59	60	56
Feb. 1	77	62	68	47	79	100	121	76	143	113	77	57	58	36	32	21	57	156	102	79	85	67	64	47
2	58	54	32	36	45	72	106	149	121	132	118	74	40	55	49	34	34	77	51	77	47	30	38	40
3	72	119	81	77	66	60	85	104	*	85	53	55	62	119	51	48	43	77	94	55	47	46	45	45
4	43	79	111	81	83	174	145	111	188	189	94	155	111	153	89	85	102	104	—	60	60	72	28	32
5	26	26	26	34	43	47	128	162	170	102	72	74	70	57	55	57	77							
19																					66	64	55	81
20	77	106	89	71	45	85	145	170	170	106	95	85	72	64	40	68	46	30	21					
23																					89	65	60	91
24	43	23	21	45	26	51	105	111	170	102	98	89	98	64	43	22	2	26	26	106	9	17	—	36
25	109	103	106	115	55	123	153	170	166	136	127	106	94	87	111	51	72	102	67	94				
Means	61	69	67	63	55	89	124	132	161	121	92	82	73	79	59	48	54	79	60	79	58	51	48	55
Mar. 9																					111	47	30	47	85
10	113	81	64	55	81	94	179	153	162	191	191	191	102	121	72	72	53	53	85	156	102	149	140	157
11	77	60	102	102	64	153	128	147	191	191	102	121	72	72	53	53	85	156	102	149	140	157		
15	51	28	17	26	68	98	191	115	119	132	81	72	81	58	54	26	9	132	85	77	77	97	81	51
17																					98	85	98	77	28
18	47	98	98	43	72	191	191	99	191	116	85	72	26	77	4	0	0	60	34	32	17	26	55	80
19	98	94	9	40	0	51	75	156	91	100	68	51	0	2	9	0	13	51						
30																				191	149	106	66	34
31	72	81	60	94	187	149	191	170	179	191	119	57	34	21	60	89	54	77	51					
Means	76	74	58	60	79	123	159	137	156	154	108	84	54	48	40	49	55	99	75	110	81	92	73	60
Apr. 4																					53	58	57	
5	51	81	61	109	111	115	132	213	204	157	94	106	30	47	64	45	85	72	81	49	45			
6																					68	60	51	
7	43	36	38	32	30	42	77	191	170	77	43	21	0	38	11	0	13	38	40					
8																				55	73	191	123	81
9	62	53	53	62	54	94	191	106	81	104	51	43	21	94	30	0	0	49	145	100	98	55	79	47
11																			21	21	19	19	26	72
12	56	60	60	55	72	155	187	153	72	55	13	36	4	21	21	13	54	47	—	38	21	38	19	17
13	43	54	32	28	30	30	145	*	152	77	34	21	0	13	0	17	26	4	40	26	28	26	21	43
14	55	47	30	34	47	68	51	55	56	38	9	38	51	55	34	21	21	26	17	13				
16																				98	85	81	64	56
17	55	62	45	47	94	111	115	98	102	106	77	64	0	17	0	0	0	36	47					
Means	55	53	48	52	63	85	128	136	114	88	46	47	15	31	13	29	19	56	50	52	66	54	51	

Table 1--Atmospheric potential-gradient in volts per meter--Concluded

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1931																								
May 6	89	109	81	81	55	81	140	166	149	125	143	128	111	94	115	109	119	100	145	74	79	77	132	104
8																			85	119		55	57	74
9	106	81	60	51	85	94	106	89	85	81	45	81	0	34	Q	43	72	62	116	102				
10																			76	70		99	106	74
11	70	66	56	46	38	42	119	77	74	104	73	45	0	21	43	Q	Q	26	87	72	98	102	87	62
12	70	96	81	67	43	191	191	102	85	123	47	45												
13																				47	52	19	34	47
14	71	64	30	38	47	117	89	85	47	51	15	Q	Q	0	0	Q	Q	0	36	45	30	49	36	30
15	50	50	34	34	30	34	89	77	85	47	34													
25																				70	153	72	59	40
26	47	43	43	50	60	115	55	93	119	94	45	19												
30																					77	94	102	60
31	74	64	79	43	17	55	98	204	187	89	72	74	70	43	40	17	*	98	106	77				
Means	70	72	58	51	47	91	111	112	104	89	59	55	56	58	40	34	48	57	98	72	82	71	77	61
June 2																				80	47	94	55	38
3	34	40	43	26	51	50	77	43	51	34	45	Q	Q	17	Q	Q	Q	72	60	29	53	38	47	49
4	45	45	54	43	49	38	60	21	89	64	72	70	63	72	70	87	85	60	51					
5																				119	70	51	94	57
6	38	119	102	34	85	102	94	149	191	149	106	115	111	106	96	83	79	72	89	85	100	66	60	55
7	55	49	45	45	43	42	72	72	89	94	98									38	42	36	30	26
8	22	19	15	15	13	17	119	106	191	121	89	45	Q	68	Q	Q	4	119	102					
10																				45	98	60	68	37
11	*	34	30	21	17	17	125	136	138	106	81	38	17	26	28	47	43	30	51					
24																				109	102	60	30	38
25	64	38	38	21	36	149	77	85	128	106	72	85	*	*	13	26	55	64	0					
Means	43	49	44	29	39	59	89	87	125	96	80	59	38	58	35	41	44	70	59	72	67	58	55	40
July 1	34	34	32	26	28	28	72	43	128	89	85	51	70	26	26	30	28	72	38	28	0	77	55	55
2	43	36	32	32	30	50	47	57	85	106	106	60	70	55	0	17	17	19	17	21	30			
6																				85	55	55	51	51
7	11	38	34	56	55	68	53	98	64	72	106	111	60	72	64	68	60	81	106	77	72	21	68	47
8	43	38	47	38	51	43	43	34	60	43	21	0	13	4	17	34	30	55	85	55				
9																					62	38	43	38
10	100	47	47	34	79	102	191	136	119	174	45	0	*	64	*	34	102	162	149	143	140	64	47	36
13											143	123	85	81	30	50	106	123	128	72	57	64	64	57
14	55	40	30	34	72	64	34	9	64															
20																					60	72	98	77
21	55	55	55	53	53	53	55	72	72	34	111	55	30	40	17	0	53	111	81	77	43	45	36	47
22	60	60	47	43	47	51	51	57	98	51	60	11	21	28	*	55	81	191	68	*				
29																94	140	191	119	72	64	51	38
30	38	30	28	21	26	38	96	128	132	77	77	51	72	60	68	*								
Means	53	42	39	35	48	55	71	70	91	88	84	47	52	42	32	34	63	106	96	75	59	36	57	50
Aug. 5		23	25	21	21	47	134	81	40	47	55	106	94	149	45	32	53	13	30	38	49	55	81	49
6	43	19	36	26	32	55	58	38	85	156	102													
7												55	45	74	60	55	55	*	34	74	28	34	40	40
8	40	38	38	36	34	54	70	85	111	77	55													
12	57	45	34	47	36	94	128	134	87	68	64	47	81	49	55	64	60	96	40	9	15	0	47	34
14	26	21	17	34	50	55	191	149	89	89	68	47	30	43	43	51	53	66	64	62	51	38	45	47
28	—	26	21	34	34	34	64	79	68	72	72	81	102	106	72	68	66	123	94	68	45	43	58	34
29	43																							
Means	42	28	28	33	31	53	104	94	80	32	69	67	70	84	55	54	57	75	62	50	58	34	50	41
Nov. 1	64	72	56	119	55	62	128	170	85	119	109	104	60	140	51	43	55	47	54	77	55	45	72	45
2	50	26	23	34	32	55	156	140	57	45	60	58	43	40	43	38	30	38	38	36	32	36	58	
8																						36	54	50
9	36	55	38	38	38	47	21	26	40	206	55	85	77	64	68	55	60	57	77	111	128	62	57	49
10	45	47	47	43	38	77	106	119	157	151	204	153	123	157	115	153	193	115	145	128	61			
12																							72	119
13	68	102	102	89	77	106	156	156	155	170	128	102	102	89	81	94	119	81	111					
Means	49	60	49	65	46	69	105	118	89	139	111	96	81	96	72	77	89	68	81	88	73	43	54	50
1932																								
Feb. 1																				128	272	145	60	47
2	98	34	81	72	85	155	117	155	215	98	123	89	143	72	66	68	124	128						
7																					60	55	40	74
8	89	106	51	170	72	113	250	277	243	264	221	243	151	166	160	102	174	145	228	158				
9																							32	30
10	45	45	43	40	45	30	49	132	145	55	60	38	15	0	43	51	43	136	26	21	15	45		
19																				204	196	200	187	277
20	277	215	198	208	162	204	145	277	277	196	170	162	155	174	109	145	132	34	26					
24																					57	47	43	68
25	64	98	77	49	62	115	196	230	119	134	157	128	98	145	68	40	55	81	77	49	55	72	47	47
26	40	57	55	62	60	45	132	179	247	277	260	170	104	94	55	51	47	57	34	52				
Means	102	92	84	100	81	110	145	208	207	170	165	138	110	109	64	76	96	97	78	95	109	94	68	91
Apr. 1																34	26	51	60	49	50	36	43	49
2	28	64	58	49	40	85	106	115	189	79	77	74	89	94	68	89	81	77	55	72	91	40	49	51
3	64	60	45	45	66	68	81	136	72	38	47	50	40	38	*									
4																				85	47	54	30	28
5	40	36	32	38	43	68	194	221	187	147	151	109	53	64	38	49	17	81	64					
6																				119	77	72	85	72
7	77	86	68	70	68	87	106	162	226	79	115	94	94	104	100	94	89	98	104					
9																				43	36	55	77	128
10	170	94	62	49	51	119	151	160	106	117	61	64	94	53	43	40	47	53	85	62	43	40	53	45
11	49	65	51	40	55	66	119	134	196	85	64	51	55	94	51	26	23	38	72					
12																					84	66	38	81
13	34	28	Q	25	64	68	80	67	49	55	34	58	47	38	54	0	51	53	49					
14																				47	33	60	64	40
15	38	53	32	30	51	85	91	85	72	70	98	70	32	45	38	34	43	53	64					
18																				98	60	45	66	60
19	47	52	28	23	21	55	170	191	64	60	60	62	51	47	55	0	21	40	57					
Means	61	58	43	38	46	77	121	140	131	80	83	68	61	65	54	44	39	60	68	69	50	50	56	62

meter above the horizontal surface of the Earth. The tree nearest the wire was about 25 feet tall and at a minimum distance of about 100 feet. A small steel tower about 35 feet high was also at a distance of about 155 feet from the wire. Other trees and buildings of considerable height were much farther removed.

The quadrant-electrometer used to measure the horizontal-wire potentials was a rather small-capacity instrument housed in a wooden box about 4 feet high located about 17 feet from the nearer post and about 3 feet from the line of the horizontal wire. The lead from the near end of the collector-wire to the electrometer-needle was nearly horizontal. The electrometer-case was earthed by an iron tube driven 4.5 feet beneath the surface of the Earth. Water was frequently poured in and around this, although the soil of the field was quite moist excepting at the very surface, the field having been irrigated well all summer. Electrometer-connections were similar to those employed in the case of the recording equipment, but the observations were made directly by means of a telescope and scale. The voltage-calibration of the instrument was made under the conditions of observation, of course. The collector appeared to be thoroughly adequate. Zero-readings were obtained nearly instantaneously upon earthing, and steady large deflections were obtained in 70 seconds after reinsulating.

On September 13 and 14, 1931, during fair weather, field electrometer-observations were recorded at intervals of 1 to 5 minutes for considerable time-intervals, the intermediate variations being indicated as well as possible. Meanwhile, the recording collector-system was earthed at frequent intervals to give definite time-reference points on the graph. Also, a new voltage-calibration of the recording equipment was made on September 14, during the horizontal-wire measurements. Association of field-electrometer and recording-electrometer readings was accomplished by identification of instantaneous values in a few instances, and by identification of average values over periods of 2 to 39 minutes of fairly constant potentials in others.

Twelve values were first selected, which yielded an average reduction-factor of 2.51. However, it was decided to discard five of these, not because of deviations from the average, but because of doubts as to identification, and possible differential effects of meteorological conditions. The average of the remaining seven was 2.35, which has been accepted as the reduction-factor by which recorded voltages have been divided to obtain the vertical potential-gradient at the Earth's surface in volts per meter.

To estimate the accuracy of the determination of the reduction-factor appears rather hazardous. The probable error of the mean value as determined on the basis of deviations of the seven individual values from the mean, is less than 1.5 per cent. However, this probably has very little significance. The chief questions are how nearly horizontal were the equipotential surfaces in the neighborhood of the horizontal-wire system, to what extent were these disturbed by the introduction of the measuring equipment, and how nearly did the potential of the insulated system approach that of the atmosphere in the immediate neighborhood of the collector. Possibly one might venture a guess that the difference between the correct value and that obtained might be of the order of 10 per cent.

Observations

Among the records secured, only those were selected which pertained to clear days. Not only were clear days selected in the meteorological sense, but records were also rejected if large negative values or long periods of rapidly oscillating potentials were recorded. This decidedly decreased the number of records considered satisfactory. However, a small number of records for a particular month does not necessarily signify persistent unsatisfactory conditions during that month, for the work had to be carried on in addition to other full-time duties, and frequently it was quite impossible to keep the equipment functioning.

In the treatment of the potential-gradient variations, values at the ends of the 24 individual hours of the day have been selected. Although, for convenience, the instantaneous value at the end of the hour rather than the average value during the hour has been selected in general, whenever the gradient was found to be varying exceedingly rapidly at any particular reading an approximate average value was recorded corresponding to an interval of a few minutes before and after the end of the hour.

Values selected in this manner have been recorded in Table 1. In this the individual hourly values as well as the monthly averages have been reduced to volts per meter. An effort was made to select only groups of approximately 24 consecutive readings. In some instances, however, digressions from this rule are apparent. For May 1931, for instance, it was exceedingly difficult to find satisfactory continuous records, because of the very frequent early afternoon disturbances yielding negative values and large and rapid fluctuations. It is believed, therefore, that the selections made are fairly representative of fair-weather conditions during that month.

In Table 1, small negative values have been assigned zero value. Such values have been indicated in each instance by an underscore. Occasional positive off-scale values have been assigned the approximate maximum value which could be recorded, and these values have also been designated by underscoring. The maximum values thus assigned varied with the sensitivity of the electrometer and position of the "zero," of course. Occasional rapid fluctuations which did not persist for sufficiently long intervals to cause records to be discarded, but which nevertheless made it impossible to assign with confidence the gradient-values for particular hours, have been designated by asterisks. When a reading was unavailable for a particular hour because of changing film, failure of the light, etc., the situation has been designated by the insertion of a dash unless the interval thus made unavailable exceeded three consecutive hours, in which case the corresponding spaces have been left blank.

The average gradient-values at the several hours of the day during each of the fourteen months are shown graphically by the first fourteen curves of Figure 5. The last two curves represent grand average diurnal-variations of the gradient, the averages having been calculated in two different manners. To obtain the "eleven-months average" values, the corresponding average values for November 1930 and November 1931 were added and divided by two, yielding an average irrespective of the number of days represented in each instance. A similar average was obtained for the pair of months, February 1931 and February 1932,
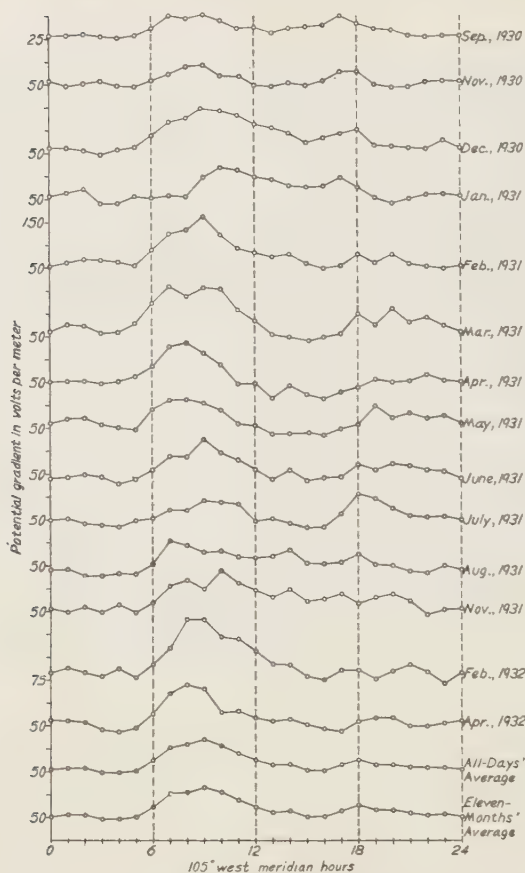
FIG. 5—Diurnal variations of atmospheric potential-gradient

and for the pair, April 1931 and April 1932. These averages were taken as representative of November, February, and April, respectively, were added to the averages for the other eight months, and the totals divided by eleven. To obtain the "all-days average" values, all individual gradient-values for a particular time of day were added, and the sum divided by the total number of values. The number of such individual hourly values recorded varied from 94 to 105.

Neither the values recorded in Table 1, nor the detailed characters of the photographic records provide indications that any considerable effect resulted from the introduction of the elaborate insulation installed February 6, 1931. It would seem, therefore, that even the original insulation was fairly adequate. There was one circumstance, however, which gave rise to some doubt as to whether conditions were entirely satisfactory at all times. During the first several months of the investigation the photographic records showed rapid response of the system

to small variations of the potential, the curves presenting a jagged appearance as shown by the photographic reproduction, Figure 6, of the record for February 19-20, 1931, a typical, clear-day, winter record. Beginning in late April and early May of that year, however, records took the form of smooth curves for periods of several hours or even whole days, with days interspersed for which the records resembled those for the winter period. Of course, it was immediately suspected that the
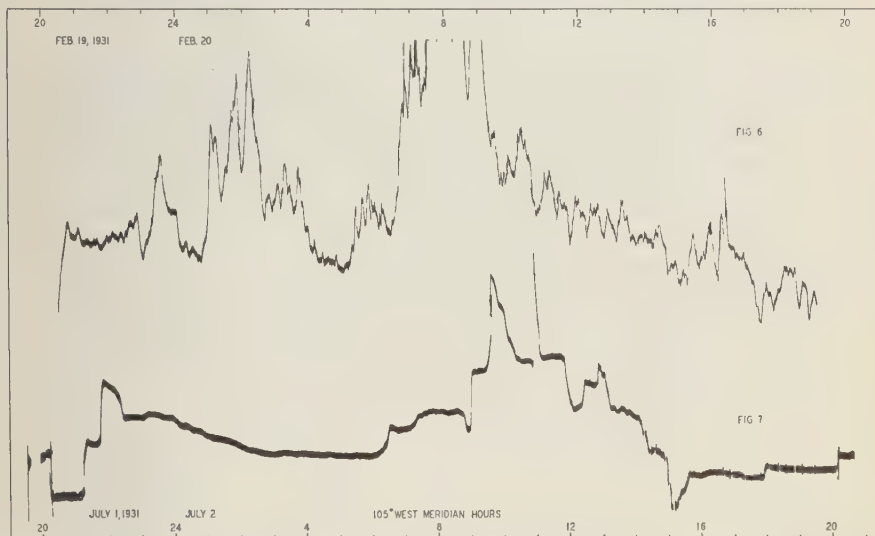
FIGS. 6 AND 7—Photographic records for February 19-20 and July 1-2, 1931

smooth curves indicated a sluggish response of the apparatus to variations of the air potential. Consequently, every effort was made to insure that the insulation and all electrical contacts were in good condition. Nevertheless, the effect persisted and became more pronounced until during June and July the smooth curves, such as that shown in the photographic reproduction, Figure 7, of the record for July 1-2, 1931, were thoroughly typical of the summer period. The effect continued through August and even into September, although many August records resembled those for the winter period, and those obtained during the calibration period, September 13-14 were decidedly of the jagged type.

During October 1931, the electrometer was dismantled, and a certain amount of corrosion found at one of the hooks supporting the needle suspension-fibre. It was therefore strongly suspected at that time that a very high resistance might have been introduced at that point, causing the needle potential to follow only slowly the variations in the collector-potential. A non-corrosive hook was then installed, and subsequent curves resembled those for the corresponding period of the preceding year. However, smooth curves again appeared occasionally during April 1932, and were very prominent in the few records obtained during May 1932. Not only were the insulation and external connections again carefully investigated, but subsequent investigation showed that in

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this instance no corrosion had occurred at the suspension-hooks. It is therefore felt that the smooth curves are probably representative of summer conditions, although it is admitted that some doubt exists due to the fact that observations were not continued through a second summer. If the effect is real, it indicates much more gradual variations of the air potential during the summer, or the lack of extraneous disturbances which may have produced the small rapid fluctuations during the greater part of the year.

Fourier analysis

To bring out the significant characteristics of the variations of the gradient, and to facilitate comparison with other investigations, the sixteen curves of Figure 5 were analyzed into Fourier series extending to the fourth or six-hour harmonic. The procedure described by Ennis[3] for the calculation and checking of the values of the Fourier constants in the expression

$$P = P_m + C_1 \sin (\theta + \phi_1) + C_2 \sin (2\theta + \phi_2) + C_3 \sin (3\theta + \phi_3) + C_4 \sin (4\theta + \phi_4)$$

was employed.

In the above expression for P, θ was measured from midnight, M. S. T. The values of the constants determined on this basis for the fourteen monthly average curves and for the two general average curves are shown in Table 2. In addition, the number of approximately 24-hour intervals for which records were retained for each month investigated is given in the table in the column headed "No. days."

To illustrate the degree to which the four-harmonic Fourier expres-

105° *west meridian hours*

sion actually represented experimental conditions, Figure 8 has been included. In this, the curve represents P as determined on the basis of the Fourier constants evaluated for the eleven-months average, whereas the circles represent the corresponding experimental values. It is seen that the four variable terms were sufficient to bring out satisfactorily the principal features of the potential-gradient time-relation.

In Figure 9 are shown the

Fig. 8—Eleven-month average values and corresponding Fourier curve

seasonal variations of the Fourier constants. To attempt to distinguish regular seasonal variations of all the Fourier constants on the basis of measurements extending over little more than a year may not seem justifiable. However, the diagram makes readily apparent the seasonal variations of the constants which were determined, and facilitates comparison with the results of other investigations, and it is believed that if one may regard the variations as really cyclic in nature, there is considerable justification for drawing the curves shown. In particular, the simple forms of the

[3]C. C. Ennis, Terr. Mag., **32**, 155 (1927).
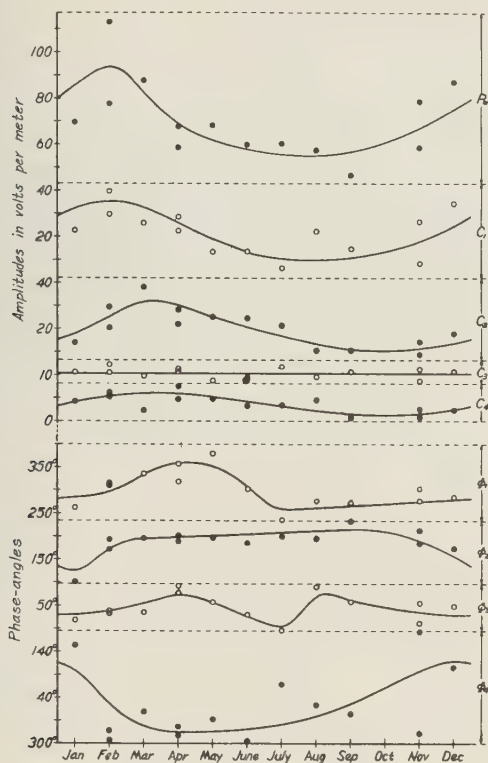
Fig. 9—Seasonal variations of Fourier constants

mean-value and amplitude curves provide some indication of a possible periodicity of those quantities.

Discussion

The curves of Figure 5 and the data of Table 1 have been given with reference to mountain standard time. In this connection, it should be borne in mind that since M. S. T. refers to the 105th meridian whereas the station was located at 105° 16′ west, M. S. T. differs from the local mean solar time by only a little more than one minute, whence the two may be regarded as identical for present purposes.

The curves of Figure 5 show that the diurnal variation of the potential gradient was characterized in general by double maxima. The morning maximum, usually the larger, occurred in the general neighborhood of 9^h, and the second maximum, when definite, in the vicinity of 18^h M. S. T. These times correspond to 16^h and 1^h, respectively, G. M. T. The late afternoon maximum appears most pronounced during late spring and summer, and actually exceeds the morning maximum in July.

The two lowest curves of Figure 5, representing average conditions,

both display the small evening maximum as well as the large morning maximum. Although it is believed that the eleven-months average curve represents average annual conditions better than does the all-days average curve, there is very little difference between the two curves. In this connection it is perhaps worth mentioning that an earlier treatment of the data in which the last three months were not included at all, and in which clear days were much less rigorously selected and no effort was made to select consecutive 24-hour periods of observation, nevertheless yielded an average curve and Fourier constants surprisingly like those obtained in the present analysis. It is felt, therefore, that the averages calculated really are representative of conditions during the period of the observations.

For many purposes, particularly the comparisons of measurements at different locations and times, the Fourier constants are of considerable significance. A study of Table 2 or an inspection of Figure 9 discloses

TABLE 2—*Fourier constants for diurnal variation in atmospheric potential-gradient, Boulder, Colorado, 1930-1932*

Year	Month	No. days	P_m	C_1	C_2	C_3	C_4	ϕ_1	ϕ_2	ϕ_3	ϕ_4
			v/m	v/m	v/m	v/m	v/m	°	°	°	°
1930	Sep.	5	46.6	14.6	10.7	11.3	1.7	273.6	232.2	58.6	4.1
1930	Nov.	7	58.7	8.2	9.0	12.4	1.7	304.0	211.8	55.2	183.0
1930	Dec.	10	87.0	34.2	17.9	11.6	4.9	285.5	173.7	48.2	104.9
1931	Jan.	10	69.4	22.8	14.0	11.1	8.5	262.7	101.0	17.0	154.1
1931	Feb.	8	77.3	29.6	20.3	11.0	12.3	314.2	192.0	38.2	327.3
1931	Mar.	6	87.6	26.0	38.0	9.5	4.6	335.2	195.4	35.2	9.3
1931	Apr.	7	58.4	28.6	28.1	11.2	9.5	356.7	201.3	92.3	336.6
1931	May	8	68.0	13.5	25.1	7.5	9.7	18.6	196.3	57.8	352.2
1931	June	7	59.8	13.5	24.5	8.8	6.6	302.4	185.2	29.8	305.5
1931	July	9	60.1	6.3	21.4	13.4	6.9	235.7	199.3	355.8	67.5
1931	Aug.	5	57.2	22.1	10.7	9.1	9.1	276.0	195.0	90.6	23.4
1931	Nov.	5	78.7	26.4	14.2	7.5	5.1	277.1	184.4	12.1	321.5
1932	Feb.	6	112.9	39.6	29.3	14.3	10.3	309.8	171.2	33.2	308.2
1932	Apr.	9	67.7	22.4	22.0	12.7	15.0	318.1	188.5	77.8	317.5
Averages											
11 months......			69.2	17.8	18.4	9.5	4.1	300.7	190.0	41.8	0.3
All days........			71.0	18.7	18.1	9.6	4.3	302.2	187.2	45.5	354.7

general seasonal variations in the Fourier constants, some of which are in agreement with variations found at many other stations. For instance, the mean-of-day gradient, P_m, and also the first harmonic amplitude, C_1, are found to be large during the winter period and small during the summer, maxima occurring about February and minima in the neighborhood of August. Similar statements may be made relative to the second and fourth harmonic amplitudes, but the maxima and minima of the C_2- and C_4-curves appear to occur a month or two later in the season than do those of the P_m- and C_1-curves. The amplitude of the third harmonic was found to remain remarkably nearly constant during the period of the investigation. Not only the numerical variation but even the percentage variation of C_3 was much less than were those of P_m and the other three harmonic amplitudes.

It is noticeable that the variations in the phase-constant of the third harmonic were also considerably less than were the variations of the

other three phase-constants determined. Because of their smallness and complicated character, it seems rather unlikely that the observed seasonal variations in ϕ_3 are truly periodic.

The upward hump in the ϕ_1-curve in the region from February to June indicates that during that season the fundamental or 24-hour term attained its maximum value somewhat earlier in the day than it did during most of the year.

A consideration of the measurements at any new station in relation to the conclusions reached by Mauchly[4] upon carefully studying the records from a great many stations on land and at sea, should be of interest. Mauchly found definite evidence that at sea-stations and even at land-stations, upon Fourier analysis, the first harmonic or 24-hour "wave" in the diurnal variations progresses approximately according to universal rather than local time. He found the average amplitude of the wave to be about 20 per cent of the mean-of-day value, and the average time of its greatest phase to occur at about $17^h.5$ G. M. T., ranging with the time of year from about 16^h to 19^h G. M. T., with much wider ranges at some land stations. In the present investigation, since ϕ_1 for the eleven-month average (the value of the phase-angle at local midnight) is $300°.7$, the maximum value of the 24-hour term corresponds to 10^h local time, or 17^h G. M. T., in close accord with the average time recorded by Mauchly. The extreme times of occurrence of the fundamental maximum range between $11^h.8$ G. M. T. for May 1931, and $20^h.3$ G. M. T. for July 1931. In connection with the ϕ_1-curve of Figure 9, this may be considered in fair agreement with Mauchly's observation that the fundamental maximum often occurred somewhat later in the day during the months of northern summer and fall than during those of northern winter and spring. Although C_1 is on the average nearer 30 per cent than 20 per cent of P_m, it should be noted that all four harmonic amplitudes are rather larger in comparison with the mean than are the corresponding amplitudes at the sea-stations and many land-stations.

Relative to the second harmonic, Mauchly found that for most land-stations (excepting those with relatively small values of C_2 C_1) ϕ_2 referred to *local* midnight was comparatively nearly constant in the region $180°$ to $200°$. In the present instance $\phi_2 = 190°$ (referred to local midnight) for the eleven-month average curve, yielding maximum second harmonic values at $20^h.7$ and $8^h.7$ M. S. T., or $3^h.7$ and $15^h.7$ G. M. T. The range of variation of ϕ_2 was from $101°$ for January 1931 to $232°$ for September 1930. It will be noted that one of the second harmonic maxima occurs about the same time of day as does the fundamental maximum, thus accounting for the very large values in the morning. Regarding comparative values of C_2 and C_1, it will be observed that C_2/C_1 was greatest during the May-June-July quarter, not because of both an increase in C_2 and a decrease in C_1, as Mauchly found generally to be the case, but simply because of low values of C_1, values of C_2 remaining near their average.

In his analysis of the observations made at sea, Mauchly found indication of a local-time wave of 6-hour period with amplitude about 3 per cent of P_m and a phase-angle of zero at local midnight, "similar to that indicated for Ebro and Kew by the investigations of Bauer and

[4]S. J. Mauchly, Terr. Mag., **28**, 61 (1923).

Chree, respectively." Remarkably like this is the 6-hour or fourth harmonic term of the eleven-months average of the present investigation, with an amplitude 6 per cent of P_m and a phase-angle of $0°.3$ at local midnight. There is a wide range of variation of ϕ_4, but this may depend upon the fact that C_4 is, in general, the smallest of the harmonic amplitudes.

All in all, there seems to be a rather surprising correspondence between the variations of the local potential-gradient and the variations of a world-wide nature brought out by Mauchly. Such correspondence was unexpected because of the supposed likelihood of large local disturbances due to the position of the station on the plains contiguous to one of the highest sections of the Rocky Mountains. It is realized, of course, that the duration of the investigation was not sufficient to determine finally the diurnal and annual characteristics of the potential-gradient variations.

During an 8-day period, August 24-31, 1929, Wait[5] made potential-gradient observations at Penalosa, Kansas, well within the central plains region. The average diurnal-variation curve obtained by him does not closely resemble the curve for August 1931 for this station. His C_1/P_m- and C_2/P_m-values are much smaller, and his C_2/C_1-value is appreciably smaller than the corresponding August values for this station. However, the G. M. T. ϕ_1-values for the two stations do not differ much, both showing 24-hour harmonics approximately synchronous with the universal 24-hour "wave."

No detailed investigation of records for other than clear days has been made. There appeared, however, to be no features characteristic of stormy weather which were not occasionally duplicated upon clear, quiet days. In general, it may be remarked that disturbed meteorological conditions, whether evidenced by wind, clouds, rain, snow, or combinations of these, were often accompanied by low or negative values or by very rapid oscillations of large amplitude sometimes extending from off-scale positive to off-scale negative values. However, it was noted that not only did these features occasionally characterize clear-day records, but records for meteorologically disturbed days sometimes appeared to be quite as regular as the normal clear-day records.

No attempt was made to keep a record of other terrestrial-electric and magnetic and meteorological conditions. However, in connection with a study of the ionization due to the cosmic penetrating radiation during a fifteen-day interval in April 1932, relations with the atmospheric potential-gradient, as well as the barometric pressure, atmospheric humidity, air-temperature, and terrestrial-magnetic character were investigated. The conclusions have been published.[6]

The writers gratefully acknowledge the kindness of the Midwest Oil Company of Denver which, through the agency of Mr. H. Aurand, supplied the photographic recorder, and of Dr. C. E. Nurnberger of the Cancer Institute of the University of Minnesota, who provided the radon tubes.

[5] G. R. Wait, Terr. Mag., **35**, 137 (1930).
[6] J. W. Broxon, G. T. Merideth, and L. Strait, Phys. Rev., **43**, 687 (1933) and **44**, 253 (1933).

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ATMOSPHERIC-ELECTRIC OBSERVATIONS OF THE POTEN-TIAL GRADIENT AT CHESTERFIELD, CANADA

By B. W. Currie

Summary—Continuous records of the atmospheric potential-gradient were taken at the Canadian International Polar Year station at Chesterfield, N. W. T., from April to August 1933 inclusive. After excluding all days with snow-drift, fog, or negative values of the potential gradient, 57 days are classed as undisturbed meteorologically. The mean hourly value of the potential gradient for these days is 68 volts per meter. The mean hourly value for each month is practically constant with the exception of April, which has an unusually low value. Analysis of the diurnal variations shows a predominating 24-hour wave with its maximum varying from 17.7 hours G. M. T., for April and May to 18.7 hours G. M. T., for June, July and August. The potential gradient is definitely higher for days with wind off Hudson Bay than for days with the wind in other directions.

Location and site of station—Chesterfield (latitude 63° 20′ north, longitude 90° 42′ west) is situated on the south shore of Chesterfield Inlet where it opens into Hudson Bay. To the east lies the wide expanse of Hudson Bay and to the west are the Barren Lands of northern Canada. For many miles inland the country is a low, rolling, rocky plain, dotted with numerous small lakes, and covered with a rocky debris originating from glacial deposits, frost erosion, and at least one submergence below the waters of the Bay. Vegetation is scanty and limited almost entirely to the peaty areas around the lakes.

Fig.1—Station-site at Chesterfield, N. W. T., June 1933; the post supporting the collector-wire can be seen to the right of living-quarters; the Bay ice is in the background; the magnetic hut is to the right

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The lakes freeze over early in October, and typical winter-conditions prevail until the end of May, when thaws become frequent. All except the largest snow-drifts disappear by the end of June. Ice begins to form on the edge of the Bay early in November and seldom leaves before the middle of July. At Chesterfield the mean distance of the edge of the floe from the shore is from four to five miles.

The station is situated on a sandy beach approximatey 200 feet from the high-tide level. A long, low, rocky ridge, running in an east-west direction sheltered the station on the north. This ridge rose very rapidly to a mean height of approximately 11 feet above the station-level at a distance of 120 feet directly north of the station. The altitude of the station above mean sea-level is 21.6 feet.

Instrumental details. —The recording electrometer used for this work was essentially a Benndorf type with some modifications by Patterson.[1] The electrometer is constructed with double-celled quadrants, and a boom with a counterpoise is attached to the axis of the double-vaned needle and the excursions of the end of the boom are registered by a bar dropping and nipping an inked thread between the boom and the recording paper, thus leaving a dot, which gives the deflection of the needle at the moment of registration. Normally this electrometer records each minute, but it was found that more accurate results were obtained by modifying the recording mechanism, so as to give a record at approximately 5-minute intervals. With the longer period a damping medium other than air was not required and in this way a loss of charge, which was affecting seriously the results, was avoided. The electrometer and recording mechanism are within a metal-lined box which is grounded in use. Leads through the walls of this box to the quadrants and needle are carried by amber-insulators.

The electrometer was placed on a bench close to a window in an unused portion of the living-quarters. Mechanical vibrations were avoided by supporting the bench by steel rods passed through holes in the floor of a diameter larger than the rods, and driven firmly into the sand below.

The two pairs of quadrants were kept generally at a potential difference of 24 volts by means of C-batteries. The electrical connections were the usual ones for this work, the midpoint of the battery being earthed. This gave a sensitivity of 3.9 v/mm. Frequent calibrations showed a practically constant sensitivity over a 180-volt range. The lead from the collectors was connected to the needle of the electrometer.

At the time when records were commenced the changing levels of snow piled against the house made it desirable to have a collector-system well removed from the walls. This was accomplished by using a 30-foot wire stretched from a conductor-and-insulation system passing through a panel in the window to an insulator fastened to an upright post. The device at the window consisted of a quarter-inch copper rod passing through the center of cylindrical sulphur insulator, 8 inches in length by 3 inches in diameter. The inner end of the rod was directly above the electrometer while the outer end was bent into a circular hook to facilitate the connection or disconnection of the stretched wire. The post-insulator consisted of a sulphur-insulator, 7 inches in length by 3 inches in diameter. Neither was sufficiently protected from the weather, so

[1]J. Patterson, Phil. Mag., **26**, 200-209 (1913).

that reliable records could not be obtained on days with much rain or fog.

Ionium-collectors of the field-type[2] were loaned for this work by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. Their numbers and corresponding activities as determined in terms of the Department's standard No. 4 were: *F*-12, 2.1; *F*-14, 1.6; *F*-43, 2.1; and *F*-31, 2.0. The first three were used continuously with the recording electrometer, and were placed together near the outer end of the stretched wire. Particular care was taken to keep the position of the group constant relative to the upright post. The height of the collector-group above the surface of the snow varied from 130-140 cm due to changing snow-conditions. After the disappearance of the snow the heights above the ground were greater than above the snow, but were within the limits of 140-150 cm.

By using the three collectors the electrometer charged very rapidly, equilibrium-conditions being attained apparently within a minute of disconnecting the electrometer-needle and collector-system from the ground. Means for measuring the capacity of the recording system were not available. The electrometer by itself has a capacity of approximately 100 cm.

Measurement of the height of the collector-system, tests for the rate of leak of the electrometer and insulation, and scraping the sulphur-insulation constituted part of the daily routine. A complete rate of leak-test consisted of removing the stretched wire from its two supporting insulators, connecting the post-insulator by a short length of wire to the conductor passing through the window insulator to the electrometer and grounding the other end. This system was then raised to a potential of approximately 200 volts and allowed to discharge for about 20 minutes. The deflection rarely decreased by more than 0.8 per cent per minute of the orginal deflection. In general it varied from 0.5 to 0.6 per cent per minute for a 20- to 25-minute period. The initial deflections were used also to detect changes in the sensitivity of the electrometer.

Standardization tests—A sandy beach about 150 yards southwest of the recording station and at an altitude about 10 feet lower than the recording station was the nearest position with a large level surface that was not close to buildings or other disturbing influences.

A modification of the leak-free method of measuring air-potentials, devised by Gish and Sherman,[3] was used in making the eye-observations. In their method, leakage of charge from the collector-system is prevented by bringing guard-rings, placed around the insulators supporting the collector-system, and the case of the electrometer to the same potential as the collector-system. A potentiometer-arrangement is used for obtaining the balancing potentials, the return of the fibers to their initial position indicating a balance. A slide-wire resistance suitable for the potentiometer was not available for our work, and the balancing potentials could only be obtained by changing the connections to the batteries.

In practice it was found that the balancing potentials could be limited to not more than three values for any one set of observations, since

²These collectors are shallow metal cups, about 5.0 cm in diameter. The ionium-bromide, spread over the inner surface, is protected from the weather by a thin coating of bakelite varnish. In use the active surface is downward.

³O. H. Gish and K. L. Sherman, Terr. Mag., **34**, 231-237 (1929).

the air-potentials were seldom found to vary by large amounts on bright afternoons with some wind. The method of decreasing the rate of leak in this way was considered advantageous despite the necessity of calibrating the electrometer each time for the measurement of the unbalanced potentials.

Collector *F*-31 was mounted approximately 1 meter above the surface at the center of a wire about 60 feet long stretched tightly between cylindrical sulphur-insulators, 7 inches long by 3 inches across. A fine wire was run from the collector to a bifilar electrometer No. 3537 (on loan from the Department of Terrestrial Magnetism, Carnegie Institution of Washington), placed about 35 feet from the collector and normal to the center of the stretched wire.

Readings were taken every minute for at least four 20-minute periods. The reduction-factor was calculated then by dividing the mean potential in volts per meter from the eye-reading electrometer for a given period by the mean potential, also in volts per meter, from the recording electrometer for the corresponding period. The mean values for each day are given in Table 1.

TABLE 1—*Summary of reduction-factor determinations*

Date	Factor	Date	Factor
1933		*1933*	
May 11	1.12	July 15	1.25
June 15	1.09	July 19	1.26
July 8	1.15	Aug. 20	1.20

During April, May, and part of June the collector-system of the recording electrometer was about 3 feet above its position in the summer because of the snow which covered the area to the west of the station and to the south of the sheltering ridge. In the higher position the shielding-effect of the station and the ridge would be reduced, and partly accounts for the lower values of the reduction-factor in May and June. The following values were used in reducing the records; April and May, 1.14; first two weeks of June, 1.15; last two weeks of June, 1.17; July and August, 1.20.

Data and results—Hourly means, centered on the half-hours, are arranged according to G. M. T. in Table 2 for 57 meteorologically undisturbed days. In making the selection days on which snowdrift, all forms of fog, or negative values of the potential gradient occurred, were excluded. Days on which rain or heavy dew may have caused the insulation to become faulty were also excluded.

The hourly means for the 20 days in April and May, the remaining 37 days in June, July, and August, and for all the days are included in Table 2. The days in April and May cover typical winter-conditions with the temperatures below the freezing-point and the ground covered with snow. With the exception of the 9 days in June the second group covers typical summer-conditions with the temperatures above the freezing-point and the ground generally free from snow.

The mean diurnal-variation of the potential gradient according to G. M. T. for each of these groups is shown graphically in Figure 2. The mean hourly value for each group, and the times corresponding

to local noon and midnight are also shown. The characteristic feature of these curves is a single minimum and a single maximum the former occurring between 3^h and 4^h, G. M. T., and the latter between 18^h and 19^h, G. M. T. A comparison between these curves and those obtained by the *Carnegie* over the oceans,[4] by the *Maud* Expedition north of Siberia,[5] and for typically arctic stations[6] shows a great similarity.

In order to obtain approximate numerical measures of the characteristic features of the diurnal variation of the potential gradient the data
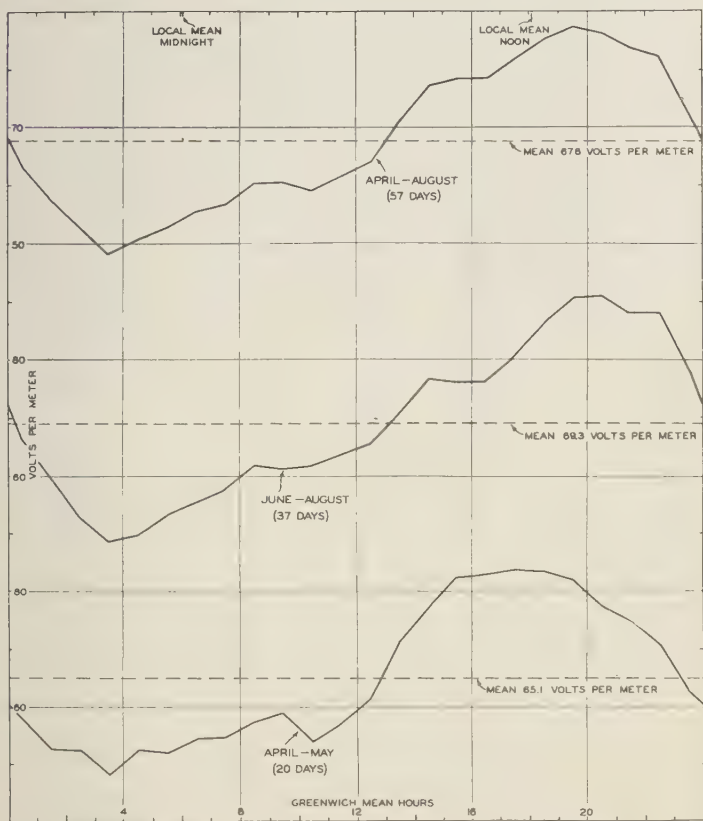
FIG 2—ATMOSPHERIC POTENTIAL-GRADIENT, CHESTERFIELD, CANADA, APRIL TO AUGUST, 1933

represented by the curves of Figure 2 have been analyzed, the Fourier constants being computed according to the formula

$$P = P_0 + \sum_{1}^{n} C_n \sin (n\theta + \phi_n)$$

[4] S. J. Mauchly, Terr. Mag., **28**, 61-81 (1923).
[5] H. U. Sverdrup, Researches of the Department of Terrestrial Magnetism, Carnegie Inst. Wash., Pub. 175, **6**, 435-460 (1927).
[6] H. Benndorf, Wien-Harms, Handbuch der Experimentalphysik, **25**, I, 282-293 (1928).

Table 2 — Mean hourly values of the atmospheric potential-gradient in volts per meter according to Greenwich mean time at Chesterfield, N. W. T., Canada

Mean hourly values for Greenwich hours

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
1933 Apr.																								
5	65	54	57	49	46	51	52	54	55	62	74	77	80	83	109	117	117	122	117	105	89	82	74	68
8	97	71	66	61	71	50	42	53	50	40	37	37	34	47	79	137	148	185	104	94	108	108	93	88
9	94	57	28	26	36	34	28	28	56	53	28	31	34	59	117	133	100	111	100	108	124	108	87	82
11	45	42	37	30	29	19	27	27	29	27	27	30	32	38	45	62	67	69	86	100	96	83	70	61
17	22	19	13	15	17	13	11	15	19	22	32	39	48	56	61	61	63	89	98	83	67	61	39	32
18	37	40	40	38	40	44	52	46	44	54	58	54	61	86	75	71	63	63	61	75	65	65	52	44
27	45	43	29	41	39	35	41	60	56	51	57	51	62	58	53	53	56	41	68	68	51	70	74	60
28	60	45	56	56	80	74	72	62	41	53	60	87	80	78	99	105	101	91	76	76	80	76	62	43
29	39	37	37	37	45	39	41	41	37	41	45	41	45	56	56	43	41	43	39	31	41	72	121	60
May																								
1	54	54	37	44	54	49	51	58	58	56	66	69	86	63	82*	87*	87	75	68	68	63	59	66	56
7	51	49	47	31	43	54	58	64	62	56	93	64	66	78	176*	172*	80	91	107	95	83	82	70	72
15	77	71	71	66	60	73	80	64	70	58	64	68	62	81	83	75	79	79	68	62	68	64	54	54
21	75	71	70	66	57	66	66	64	71	67	60*	74	64	58	64	71	64	67	74	78	81	87	103	71
23	60	93	87	79	123	93	84	73	54	126*	168*	68	63	89	80	79	75	75	86	75	75	66	66	72
24	69	65	50	50	53	65	53	60	103	98	62	64	60	81	59	65	57	59	57	57	57	55	52	50
25	49	44	50	44	46	44	67	56	77	75	58	74	110	107	109	109	116	107	105	96	95	95	88	89
28	38	28	28	28	28	42	61	75	67	67	37	15	33	58	47	51	72	58	105	123	72	68	53	86
29	67	61	138	90	82	78	82	73	94	123	56	70	84	109	126	94	94	68	68	61	58	49	51	27
30	55	68	74	80	67	74	65	76	76	81	77	83	70	86	65	80	99	94	85	85	77	72	61	68
31	57	41	35	35	41	46	60	55	31	33	35	48	48	54	61	72	81	90	100	105	100	76	72	76
June																								
7	86	79	79	72	72	94	97	101	96	105	99	103	105	98	105	98	98	81	77	83	94	74	74	53
12	94	74	62	68	66	62	68	75	73	75	75	73	75	75	90	88	86	81	88	81	75	77	78	97
15	76	62	57	58	59	61	62	70	76	87	91	66	74	72	85	89	108	114	121	102	129	127	115	72
18	152	132	118	130	132	128	138	145	139	106	87	85	93	107	111	106	106	117	117	128	137	126	123	111
24	44	41	40	37	52	37	47	47	38	37	47	43	38	49	77	86	96	94	97	81	99	86	69	86
25	67	53	38	34	48	50	48	53	50	48	53	59	51	61	61	62	58	54	61	54	70	64	58	66
26	57	51	54	45	40	55	42	43	52	48	50	48	51	54	68	79	77	74	66	62	69	66	58	66
28	105	73	45	39	31	34	37	29	22	29	33	50	48	56	54	63	60	60	54	64	63	50	38	32
29	31	30	28	24	24	21	18	30	28	33	38	38	41	43	53	54	48	65	65	126	84	70	65	46

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Month	Day																								
July	1	53	72	75	76	84	78	82	38	20	90	93	81	63	57	48	51	53	51	48	50	43	34	34	41
	2	123	214	111	94	131	177	138	103	116	123	98	85	53	51	64	65	60	60	56	59	73	78	68	60
	3	67	105	97	85	72	67	75	72	63	54	56	52	52	45	43	43	43	45	43	47	47	45	45	58
	8	113	105	100	94	88	96	81	68	80	89	75	58	58	49	76	67	44	36	32	28	14	14	10	10
	11	39	46	53	77	53	50	56	62	64	59	61	69	72	66	69	35	59	70	61	59	43	45	51	82
	12	58	72	107	162	124	89	64	60	53	50	38	34	37	40	37	57	35	26	20	20	20	24	32	34
	13	63	64	80	85	88	84	87	84	85	77	84	72	69	65	62	44	54	51	43	46	54	57	62	60
	14	148	140	155	163	160	158	139	178	110	115	72	47	72	56	89	95	44	51	48	39	38	47	60	63
	17	98	104	98	96	101	96	87	90	92	84	98	107	96	95	52	59	98	92	89	66	68	62	77	108
	18	41	52	44	17	81	75	79	75	84	97	95	92	87	76	65	94	65	75	71	71	87	89	92	97
	19	56	62	65	54	57	57	54	52	60	57	54	50	45	51	68	70	46	37	41	40	38	29	44	59
	24	56	55	58	63	73	75	60	46	60	63	68	80	81	73	51	50	70	58	46	38	41	50	51	53
	25	74	116	109	122	100	56	48	58	50	50	53	54	57	53	53	52	47	47	45	42	41	42	47	52
	26	97	103	74	81	80	59	64	41	53	58	68	64	52	52	51	41	51	39	39	31	30	23	38	61
	29	62	73	101	87	101	76	44		47	65	57	33	50	54			40	40	46	38	46	49	50	50
	31																								
Aug.	2	71	76	74	72	75	81	72	66	69	56	45	39	35	34	44	39	41	39	37	39	35	37	45	59
	3	104	111	107	104	117	60	70	72	64	52	46	46	46	46	44	44	44	44	44	38	36	39	52	54
	5	68	73	78	70	68	78	70	58	187	172	146	91	120	85	96	57	50	47	44	39	38	42	63	100
	7	152	159	96	80	90	85	54	67	49	66	66	67	68	68	57	42	24	16	20	33	49	48	48	38
	12	107	115	105	87	85	73	79	77	77	80	98	87	87	85	92	92	83	62	65	60	63	75	74	77
	13	125	97	109	113	107	142	160	135	114	105	70	67	62	60	63	62	63	67	74	76	76	97	158	107
	15	60	65	88	93	85	81	73	70	73	77	73	86	78	71	70	71	71	76	78	58	38	65	71	73
	17	58	73	73	91	75	79	83	81	79	76	63	68	51	68	37	43	50	51	45	36	38	38	50	53
	18	63	69	68	69	69	74	84	71	71	69	49	56	56	58	56	61	50	47	29	19	23	29	40	50
	27	189*	103	90	90	106	108	72	56	64	56	64	69	67	57	70	84	70	70	69	54	51	51	62	57
	30	71	82	99	99	96	81	67	48	39	46	57	71	61	74	81	84	89	79	77	69	67	105	69	72
	31	64	74	74	81	81	82	77	79	67	69		51	51	59	61	60	56	53	53	61	57	60	67	67
Sep.		97	117	134	149	155	140	135	118	107	95	83	75	70	71	64	78	52	73	64	59	37	61	58	39
Means	Apr.-May	62.4	70.4	74.9	77.5	82.2	83.6	83.8	83.0	82.4	77.4	71.2	61.1	57.2	54.0	58.8	57.5	54.6	54.6	52.1	52.8	48.3	52.5	52.6	57.8
	June-Aug.	78.2	88.5	88.2	91.2	90.6	86.6	80.7	76.3	76.3	77.0	71.0	65.7	63.8	62.2	61.4	62.0	58.7	55.6	53.2	49.7	48.7	52.8	59.7	66.3
	All days	72.6	82.2	83.6	86.5	87.6	85.5	82.0	78.5	78.4	77.1	71.0	64.0	61.5	59.2	60.5	60.4	56.7	55.3	52.2	50.8	48.5	52.7	57.4	63.2

* The values so marked are not included in means.

θ being counted from 0^h, midnight, G. M. T., at the rate of 15° per hour. The results for the first four waves are given in Table 3. A column is included in the Table for $G^1{}_m$, the time of the maximum of the 24-hour wave. Following Mauchly[4] the ratio C_2/C_1 is also given.

TABLE 3—*Results of Fourier analysis of the diurnal variation of atmospheric potential-gradient at Chesterfield, N. W. T.*

Period	P_0	ϕ_1	ϕ_2	ϕ_2	ϕ_4	C_1	C_2	C_3	C_4	$G^1{}_m$	C_2/C_1
1933	v/m	°	°	°	°	v/m	v/m	v/m	v/m	h	
Apr.-May	65.1	185	259	126.5	274	16.4	4.4	2.2	1.2	17.7	0.27
June-Aug.	69.3	170.5	178	161	303.5	17.3	6.8	2.8	0.9	18.7	0.39
All days	67.8	175.5	195	151	293	16.9	4.9	2.5	1.0	18.3	0.29

The predominating effect of a 24-hour wave is shown by the analysis. The time of its maximum value increases from $17^h.7$ G. M. T., for the spring to $18^h.7$ for the summer. The ratio C_2/C_1 also shows an increase. Comparison of these results with the analysis of Mauchly[4] of the observations of potential gradient from the cruises of the *Carnegie* and from Karasjok (latitude 69°.3 north) shows a very good agreement.

Definite conclusions concerning the annual variation of the potential gradient at Chesterfield cannot be made. The mean hourly values in volts per meter for each month and also for the total period as computed from the data given in Table 2 are as follows: April, 60; May, 69; June, 71; July, 67; August, 71; all days, 68. With the exception of April the monthly values are practically constant. The low value of the potential gradient in April is unexpected, since all stations in the northern hemisphere find higher potentials during the winter and spring months than during the summer. Loss of charge through insulation-leakages, and a decrease of the activity of the collectors by frost-films did not seem to be serious. The rate of leak in the insulation-tests was lower for April than for the succeeding months. On occasions in April when frost films on the collectors were suspected, and the suspected film removed by taking the collectors indoors and drying before replacement, no noticeable increase in the deflection of the recording electrometer could be detected.

Meteorological effects on the potential gradient—The meteorological effects of most frequent occurrence are listed below.

(1) Large positive potentials during snow-drift. Sign of the potential and its magnitude not affected by removal of collectors from the stretched wire during high drift.

(2) Low values of the potential and sometimes negative values at the end of a long period with snow-drift.

(3) Large positive potentials with all forms of fog or mist.

(4) Negative values of the potential at the beginning of rains.

(5) Values of the potential above the mean occurred as frequently as values below the mean for days with low continuous cloud (altitude 300-600 meters).

(6) Higher values of the potential gradient occurred on days with winds off Hudson Bay than on days with winds from other directions. This is shown in Table 4. Twelve hourly periods extending from either

0^h to 12^h G. M. T., or 12^h to 24^h G. M. T., were selected from Table 2 during which the wind had blown continuously from the northeast-southeast quadrant. The differences between the sum of the hourly potentials for a given period and the sum of the mean hourly potentials for all the corresponding periods in the month were then found, and the mean hourly difference $\triangle P$, for each month was then calculated. The positive sign in the table indicates an increase in the potential gradient.

TABLE 4—*Mean hourly increase in the potential gradient for 12-hour periods with eastern winds, at Chester-field, N. W. T.*

Month	Total No. periods	ΔP
1933		v/m
April	5	+12.0
May	8	+ 8.0
June	4	+30.0
July	3	+10.0
August	6	+29.0

This increase in the potential gradient is to be expected since the winds from Hudson Bay are likely to bring water-droplets and salt-particles which would reduce the conductivity of the atmosphere by absorbing the small ions and becoming large ions of low mobility.

REVIEWS AND ABSTRACTS

KELLER, W. D.: *Earth-resistivities at depths less than one hundred feet.* Bull. Amer. Ass. Petrol. Geol., Tulsa, Okla., v. 18, No. 1, 1934 (39-62).

This paper gives the results of resistivity-measurements in central Missouri, made primarily to determine the specific resistivities of soil and rock materials and also, in part, to test out the efficacy of such measurements in detecting structural changes in comparatively simple structures. The four-electrode method with commutated direct current was used. The formations examined were shales, sandstones, limestones, alluvium, gravel, and some igneous rocks.

The resistivity-values are reported not in standard units such as ohms per centimeter cube or meter-ohms but in a field-unit, stated as being ohms per foot cube but which is actually 2π times that unit. However, if the reported values are multiplied by 2 they approach closely enough to the convenient and increasingly used meter-ohm unit values so that they can be readily compared with the records obtained by others.

The specific resistances reported are for the most part quite in line with the scant data previously collected although the variations recorded in the resistivity of a given formation are rather greater than would be expected. It is probable that this is due in part, at least, to the effects of the overburden and the underlying structure in certain of the measurements. The maximum values shown for the limestones and sandstones for instance, appear to be somewhat too great while the values for igneous rock seem rather low in some cases. As a result the author classifies these sedimentaries with the gravels and igneous rocks while our experience indicates that their resistivities are at most intermediate between those of the shales and the igneous rocks. The importance of the moisture-content of rocks, particularly of the sedimentaries, on their resistivities is again brought out in the records.

The tests of the method as a prospecting device are simply and adequately carried out. The author's interpretations are avowedly based on first approximation and no attempt is made to work out exact formulas or to make general applications of the results. Unlike many who enter this field the author does not aim at the development of a method which will be absolute, unique, and self-sufficient but points out that the greatest value of the method lies in its use to supplement and fill in the gaps in geological information about a region by combining the resistivity-data with knowledge otherwise obtainable.   W. J. ROONEY

WEAVER, PAUL: *Relations of geophysics to geology.* Bull. Amer. Ass. Petrol. Geol., Tulsa, Okla., v. 18, No. 1, 1934 (3-12).

On the basis that the most important objective in present geophysical work is the mapping of subsurface contours, the author compares the different methods in their essential characteristics. Of the four principal methods used, gravitational, magnetic, electrical, and seismic, the first three are forms of measurement of a potential function while the last, the seismic method, is not. He holds that the potential-function methods have their greatest value in reconnaissance geology and that in detailed mapping of contours at great depths they are at a disadvantage when compared to the seismic method; first, because of the inverse-square law and second because of the surface extension required in such measurements. Using the seismic method the chief difficulty encountered is that due to variations in the principal characteristics of the intervening rocks. Information concerning these physical characteristics, and the effect on them of folding, faulting, non-uniform sedimentation, and such factors are necessary for more precise mapping and can be best secured by cooperation of geophysicists and geologists.
                                                           W. J. ROONEY

MESSUNGEN DER EXHALATION VON RADIUMEMANATION AUS DEM ERDBODEN

Von P. Reginald Zupancic

Abstract—The amount of radon given off from the soil was measured by a new method. An area of 2800 cm² of lawn was covered by a zinc cylinder filled with air completely free of radon at the beginning of each experiment. Twelve or 24 hours later the air from the cylinder after thorough mixing was introduced in an ionisation-vessel calibrated in curies and measured in the usual way. From this measurement the amount of radon exhaled from the soil per square centimeter and second can be calculated. The average amount of this exhalation of radon as observed in the period December 1932 to July 1933, was 23×10^{-18} curie per cm² per sec. Within the period mentioned the minimum of exhalation was found in January and the maximum in June. The exhaltation during the day is about 1.5 times as much as in the night hours. The maximum value of exhaltation during the observation-period of about six months exceeds the minimum by about 100 times. Exhalation of radon is mainly governed by the temperature of the soil, increase of this temperature causing an increase of exhalation of radon. Freezing of the soil decreases the amount of exhalation almost to zero. Atmospheric pressure and its variations seem to be of secondary importance.

Zusammenfassung—Die Exhalation von Radiumemanation aus dem Erdboden wurde nach einem neuen Verfahren quantitativ untersucht: Auf die zu untersuchende Stelle des Bodens wurde ein grosses Metallgefäss mit der Öffnung nach unten eingesetzt und die darin enthaltene Freiluft bei Beginn des Versuches durch Einleiten emanationsfreier Luft aus einem Pressluftzylinder verdrängt. Nach 12 bis 24 Stunden wurde die in dieser Zeit ins Gefäss eingetretene radonhältige Luft nach gründlicher Durchmischung des Gefässinhaltes in eine in curie geeichte Ionisationskammer übergeführt und im radioaktiven Gleichgewicht gemessen. Daraus wurde die mittlere Exhalation berechnet. Für die erste Jahreshälfte ergab sich ein Mittel von 23×10^{-18} curie/qcm sec. Es zeigte sich ein ausgeprägter Jahresgang mit dem Minimum im Jänner und dem Maximum im Sommer. Es konnte festgestellt werden, dass die Exhalation bei Tage ungefähr 1½ mal so gross ist wie bei Nacht. Das Verhältnis zwischen grösstem und kleinstem Wert im Laufe der Untersuchung war 1:100. Die Exhalation erwies sich als sehr stark abhängig von der Bodentemperatur: Eine Erwärmung des Bodens bringt eine Erhöhung der Exhalation mit sich. Einen geringeren Einfluss üben Luftdruckschwankungen aus. Überaus stark wird sie durch das Gefrieren des Bodens behindert.

§1—Einleitung

Die Ionisation der Luft über festem Boden hat zum grössten Teil ihre Ursache in den Emanationen und deren Zerfallsprodukten. Daher ist es von Interesse direkt zu untersuchen, ob die aus dem Erdboden strömenden Emanationen ausreichen, um den Emanationsgehalt der Luft trotz des radioaktiven Zerfalls aufrecht zu erhalten. Da dies vorerst nur für Radon direkt durchgeführt werden kann, (die Zerfallsgeschwindigkeit des Thoron ist so gross, dass man hiefür indirekte Methoden heranziehen muss) sei im Folgenden die Untersuchung auf die Radiumemanation beschränkt.

V. F. Hess und W. Schmidt[1] haben 1918 eine Theorie aufgestellt, die jene Emanationsmenge zu berechnen erlaubt, die pro qcm und Sekunde dem Boden entströmen muss, um den Emanationsgehalt der Freiluft ganz durch die Nachlieferung aus der Erde erklären zu können. Diese pro Zeit- und Flächeneinheit aus dem Boden in die Freiluft beförderte Emanationsmenge, die wir kurz "Exhalation" benennen wollen, sollte danach etwa 24 bis 33×10^{-18} curie/qcm sec betragen.

[1] V. F. Hess und W. Schmidt, Physik. Zs., **19**, 109 (1918).

W. Schmidt[2] modifizierte 1926 diese Theorie und kam zu wesentlich kleineren Werten der Exhalation, nämlich 0.8 bis 3.0×10^{-18} curie/qcm sec. Eine Revision dieser neueren Theorie wurde 1931 von J. Priebsch[3] vorgenommen, der unter plausiblen Annahmen zu dem Ergebnis kam, dass bei mittleren Verhältnissen etwa 20×10^{-18} curie qcm sec dem Erdboden entquellen. Es ist dies beinahe derselbe Wert, der sich nach der ersten theoretischen Berechnung von Hess und Schmidt ergeben hatte.

Die ersten Versuche, die Exhalation experimentell zu bestimmen, stammen von H. Ebert[4], sind aber quantitativ nicht brauchbar. Exakte Messungen stellten 1912 J. Joly und L. B. Smyth[5] in Dublin und im Jahre 1915 J. R. Wright und O. F. Smith[6] in Manila an. Die von ihnen ausgearbeitete Methode ist indessen ziemlich umständlich und zeitraubend. In neuester Zeit hat W. Kosmath[7] Versuche in Liebenau bei Graz, Steiermark, nach einem im Wesen gleichen Verfahren ausgeführt, nur ohne Anreicherung des Radons in Kohle, deren Ergebnisse indessen noch nicht veröffentlicht sind.

Diese wenigen Versuche sind die einzigen geblieben, die sich mit der experimentellen Bestimmung der Exhalation direkt beschäftigen, und doch wären für einen gut brauchbaren Mittelwert zahlreiche Messungen nötig, da mit dem wechselnden Radiumgehalte des Bodens auch die Exhalation Schwankungen unterworfen ist.

Eine wesentlich einfachere Versuchsanordnung wurde über eine Anregung von Professor Hess gebaut, die sich in ihrem Grundgedanken an eine Methode anschliesst, die von E. Schmid[8] in Graz zur Untersuchung des Emanationsgehaltes von Kellerluft verwendet wurde.

§2—Beschreibung der Methode

Während Joly und Smyth die Adsorption an Kokosnusskohle verwendeten, um die Radonmenge anzureichern, die in einem bestimmten Zeitraum aus dem Boden trat, wurde hier diese Emanationsmenge direkt in einem grösseren Blechgefäss gesammelt. Dazu wurde es über den Boden gestülpt und vor dem Versuche mit vollkommen emanationsfreier Luft aus einem Pressluftzylinder gefüllt. Der einfache Bau des Sammelgefässes ist aus der Abb. 1 ersichtlich. Es besteht aus einem Zylinder von verzinktem Eisenblech mit einem Durchmesser von 60 cm und einer Höhe von 35 cm; die Grundfläche hatte also ein Ausmass von 2820 qcm.

Diese Abmessungen wurden gewählt, um auch bei den kleinen Wintereffekten eine genügende Menge an Emanation angesammelt zu bekommen, die mit der unten beschriebenen elektrometrischen Anordnung noch genau genug gemessen werden konnte. In der Mitte der Deckfläche ist ein Windrad W angebracht, das von aussen her mittels einer luftdicht eingesetzten Kurbel K in rasche Umdrehungen versetzt werden kann und die Luft im Gefäss gut durchmischt. Fünf cm vom oberen Rande entfernt sind an gegenüberliegenden Stellen zwei Metall-

[2]W. Schmidt, Physik. Zs., **27**, 371 (1926).

[3]J. Priebsch, Physik. Zs., **32**, 622 (1931).

[4]H. Ebert, Physik. Zs., **10**, 364 (1909).

[5]J. Joly und L. B. Smyth, Phil. Mag., **24**, 632 (1912).

[6]J. R. Wright und O. F. Smith, Phys. Rev., **5**, 459 (1915).

[7]W. Kosmath, Beitr. Geophysik, **40**.

[8]E. Schmid, Zs. Geophysik, **8**, 5 und 233 (1932).

hähne H_1 and H_2 eingesetzt; ein dritter H_3 befindet sich auf der einen Seite 15 cm über dem unteren Rande, ihm gegenüber eine grössere Öffnung mit ungefähr 5 cm Durchmesser, die einen 2 cm langen luftdicht verschraubbaren Rohrstutzen R trägt.
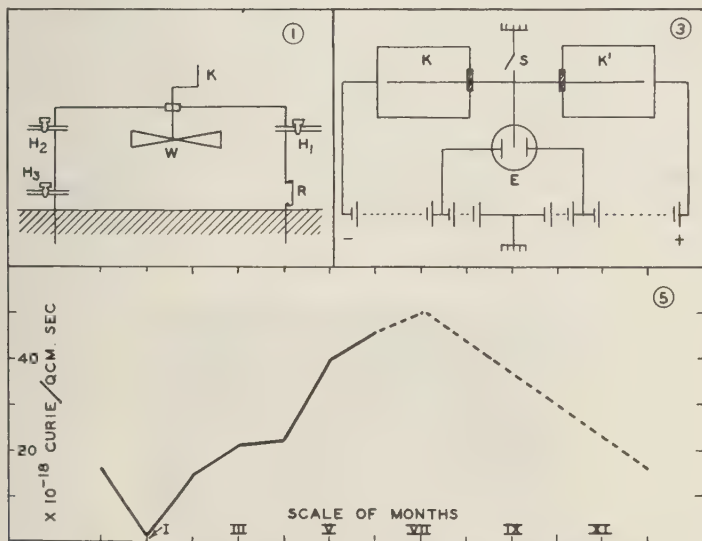
ABB. 1, 3, UND 5—Schematische Zeichnung des Sammelgefässes; Elektrometrische Anordnung, Schaltungsskizze; Jahreskurve der mittleren Exhalation

Das Sammelgefäss wird 10 cm tief in die Erde eingegraben, wobei natürlich die Bodenfläche innerhalb des Gefässes nicht verletzt werden darf, damit die Bodenkapillaren in ihrem ursprünglichen Zustande erhalten bleiben. Rings um den eingesenkten Zylinder wird die Erde festgestampft, um einen möglichst dichten Abschluss zu erreichen. Bei H_1 ist ein offenes Glasrohr angeschlossen, das mit ausgeglühter Kokosnusskohle gefüllt ist, damit sich der Luftdruck ausgleichen und trotzdem keine Emanation von aussen eintreten kann. Es genügt wohl auch ein kurzes Rohr mit etwas festgestopfter Watte, da bei den gewählten Abmessungen die mit den kleinen Freiluftmengen eintretende Emanation keine merkbare Vergrösserung der im Gefäss bereits angereicherten Emanationsmenge bewirken wird.

Im Allgemeinen wird nun durch die Grundfläche, über der sich das Gefäss erhebt, pro Sekunde eine gewisse Emanationsmenge einströmen, gleichzeitig aber ein Teil der angesammelten Emanation durch den radioaktiven Zerfall wieder verschwinden. Treten durch 1 qcm Bodenfläche in der Sekunde q curie ein und beträgt die Grundfläche f qcm, so werden pro Sekunde qf curie nachgeliefert. Die Änderung der angesammelten Emanationsmenge Q ergibt sich dann zu

$$dQ/dt = qf - \lambda Q$$

wobei λ die Zerfallskonstante der Radiumemanation bedeutet. Über das endliche Zeitintervall T integriert erhält man

$$Q_2 - Q_1 = qfT - \lambda\overline{Q}T$$

Dabei bedeuten Q_1 und Q_2 die zur Zeit T_1 bzw. T_2 vorhandenen Emanationsmengen; $\overline{Q}$ ist die mittlere Emanationsmenge während der Ansammlungszeit T. Näherungsweise kann für $\overline{Q}$ das arithmetische Mittel $(Q_1 + Q_2)/2$ eingesetzt werden. Es ergibt sich somit die Exhalation zu

(1) $$q = (Q_2 - Q_1)/Tf + (\lambda/f) \; [(Q_2 + Q_1)/2]$$

in curie qcm sec. Diese Formel vereinfacht sich noch sehr, wenn, wie es bei meinen Versuchen der Fall war, zur Zeit $T = 0$ die Emanationsmenge $Q_1 = 0$ ist; in diesem Falle wird

(2) $$q = Q_2/Tf + \lambda Q_2/2f$$
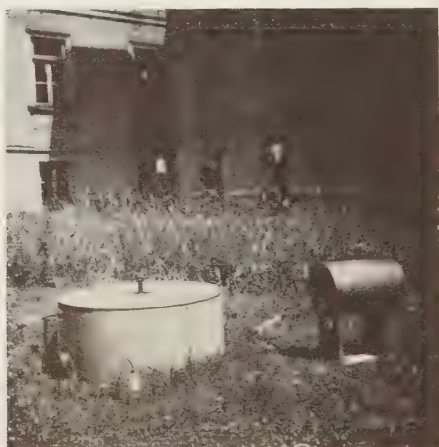
ABB. 2—Das Sammelgefäss beim Absaugen der Luftprobe

Von Zeit zu Zeit muss die angesammelte Emanation aus dem Sammelgefäss entfernt und der Anfangszustand $Q_1 = 0$ wieder hergestellt werden; denn bei längerer Ansammlungszeit würde unsere Näherung $\overline{Q} = (Q_1 + Q_2)/2 = Q_2/2$ nicht mehr gelten. Dazu wurde das Sammelgefäss mit Pressluft gefüllt, die aus einem Zylinder stammte, der bereits wenigstens vier Wochen gefüllt war. So war in einfachster Weise dafür gesorgt, dass die etwa anfangs in der Pressluft vorhandene Radonmenge durch ihren natürlichen Zerfall verschwunden war. Beim Einfüllen der Pressluft erwies sich folgender Vorgang als vorteilhaft:

Einige Zeit, mindestens eine Stunde vorher werden schon alle Hähne und der Rohransatz R geöffnet. Bei H_2 wird der Schlauch angeschlossen, der von der Pressluftbombe zum Gefässe führt, und Pressluft mit einer

Geschwindigkeit von 25 lit/min 6 Minuten hindurch eingeblasen. Bei den Kontrollversuchen ergab sich, dass dann der Emanationsgehalt im Gefässe praktisch gleich Null war. Nach dem Ausblasen werden die Hähne und R geschlossen, nur H_1 bleibt offen, der das oben beschriebene Rohr mit Watte oder Kohle trägt. Die Luft im Gefässe wird öfters mit dem Windrade kräftig durchmischt.

Als Ansammlungszeiten wurden gewöhnlich 24 Stunden genommen; bei gefrorenem Boden und daher sehr kleinen Effekten öfter auch 2 bis 3 Tage. Diese verhältnismässig langen Ansammlungszeiten wurden nur aus dem Grunde gewählt, um wirklich verlässliche Werte für die mittlere Exhalation pro Tag zu erhalten. Elektrometrisch wäre es bei unserer Anordnung natürlich ein Leichtes gewesen, vielmal kleinere Effekte zu bestimmen.

Zur Messung der Emanationsmenge diente eine elektrometrische Differentialschaltung, ähnlich derjenigen, die von Frl. H. Rösner[9] im gleichen Institut gebaut worden war. Es werden zwei genaue gleiche Ionisationsgefässe verwendet, deren Innenelektroden dauernd untereinander und mit dem Schlingensystem des Messinstrumentes, eines Einschlingenelektrometers nach Kohlhörster, verbunden sind.

An die Wände der beiden Kammern K und K' (Abb. 3) wurde eine entgegengesetzt gleiche Spannung von $\pm$ 110 Volt gelegt, sodass bei gleicher Ionisation der beiden Gefässe keine Aufladung des Elektrometers E resultiert. Wurde in eines der beiden Gefässe Radon eingebracht, so konnte es durch die Wanderungsgeschwindigkeit des Fadens gemessen werden, ohne dass Aenderungen des Reststromes—Schwankungen der Umgebungsstrahlung und der Ultrastrahlung während der Messung—Störungen verursachen könnten. Mittels zweier Radiumnormallösungen mit einem Gehalt von 7.92×10^{-11} g bzw. 15.84×10^{-11} g Ra wurde der Apparat in curie geeicht; damit war erreicht, dass die Messungen von ungenügender Sättigung im Ionisationsgefäss und eventuellen Ungenauigkeiten einer Kapazitätsbestimmung unabhängig wurden. Um jede Belastung des Isolators durch Aufladung zu vermeiden, wurde bei der elektrometrischen Messung der bekannte Kunstgriff angewendet, unmittelbar nach Aufhebung der Erdung des Innensystems eine kleine Hilfsspannung von entgegengesetztem Vorzeichen an dieses zu legen, sodass der Faden z. B. von Skalenteil -10 bis $+10$

[9] H. Rösner, Dissert., Innsbruck, 1931.
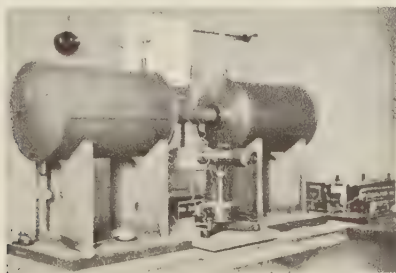
ABB. 4—Elektrometrische Anordnung, Ausführung

wandert und die mittlere Spannung während der Messung Null bleibt. Eichungen wurden öfters und nach verschiedenen Ansammlungszeiten durchgeführt. Dabei wurden immer gut übereinstimmende Werte gefunden, wie die Tabelle 1 zeigt, ein schöner Beweis für die Zuverlässigkeit und Haltbarkeit dieser von der Phys.-Techn. Reichsanstalt zu Charlottenburg hergestellten Lösungen. Der Stromwert bezieht sich natürlich auf Radon samt den kurzlebigen Zerfallsprodukten.

TABELLE 1

Datum	Lösung	Ansammlungsdauer				Stromwert in el. stat. Einheiten
16.3.	1	9 Tage,	16	Stunden		3.42×10^6
20.3.	1	4 "	0.7	"		3.37×10^6
31.3.	1	10 "	17	"		3.48×10^6
21.4.	1	20 "	23.3	"		3.47×10^6
1.5.	1	10 "	2	"		3.49×10^6
8.5.	2	3 "	0	"		3.48×10^6
29.7.	1	16 "	17	"		3.48×10^6

Es entspricht daher bei unserer Anordnung (Kapazität 15.9 cm, Empfindlichkeit 35 Skalenteile pro Volt) einer Aufladegeschwindigkeit von 1 Skalenteil pro Minute eine Gleichgewichtsmenge von 7.1×10^{-12} curie im Gefäss.

Vor der Messung wurde die sehr geringe "natürliche Aufladung," d. h. der Differenzeffekt zwischen den Ionisationen in beiden Gefässen, gemessen; sodann wurde jenes Gefäss, das mit der Luftprobe gefüllt werden sollte, evakuiert und mit dem Sammelgefäss verbunden. Dabei wurde zum Reinigen und Trocknen der Luft ein Wattefilter und eine Chlorkalziumvorlage in den Luftweg geschaltet. Ersatz für die abgesaugte Luft konnte durch den Hahn 1 eintreten, sodass jede Saugwirkung auf den Boden vermieden war. An die gefüllte Kammer wurde nun eine Spannung von -110 Volt gelegt, während die Innenelektrode geerdet blieb. Nach drei Stunden, sobald sich also das radioaktive Gleichgewicht eingestellt hatte, wurde die Aufladegeschwindigkeit des Elektrometers als Mittel aus 10 Ablesungen festgestellt. Damit war die Radonmenge im Ionisationsgefäss bestimmt und brauchte nur mehr mit dem Faktor V/v ($V = 70.680$ ccm Volumen des Sammelgefässes, $v = 8790$ ccm Volumen des Ionisationsgefässes) umgerechnet zu werden, um die im Sammelgefäss nach Beendigung der Ansammlungszeit vorhandene Radonmenge Q_2 und damit nach der Formel (2) die Exhalation q in curie/qcm sec zu ergeben.

Als Versuchsplatz wurde ein rasenbedeckter Teil vom Hofe des Physikalischen Institutes der Universität Innsbruck gewählt. Das Sammelgefäss wurde einige Meter vom Gehweg entfernt aufgestellt und blieb den ganzen Winter über ungestört an seinem Platze, sodass ein dichter Abschluss gewährleistet war, dessen Notwendigkeit sich in Vorversuchen herausgestellt hatte, sollte ein Entlüften des Gefässes verhindert werden. Dadurch wurde es aber unvermeidlich, dass das Gras verkümmerte und die natürlichen Bodenverhältnisse etwas abgeändert wurden. Vergleichende Messungen auf Rasenboden in unmittelbarer Nähe des gewöhnlichen Versuchsplatzes und auf einer Gar-

tenwiese in Hötting im Frühling ergaben, dass kein wesentlicher Unterschied in der Exhalation an diesen verschiedenen Orten besteht. Dies zeigt, dass ein längerer Abschluss der Versuchsfläche durch das übergestülpte Gefäss die mittlere Exhalation jedenfalls nicht stark ändert.

§3—ERGEBNISSE

(1) *Jahresgang und Mittelwert*

(*a*) *Monatstabelle*—

TABELLE 2

Monat	Exhalation, q, in 10^{-18} curie/qcm sec			Verhältnis q (max)/q (min)	Zahl der Messungen
	Mittelwert	Maximum q (max)	Minimum q (min)		
Dezember	16	36	6	6	7
Jänner	1	2	0.6	3.5	7
Februar	15	48	3	16	10
März	21	34	8	4.2	13
April	22	27	17	1.5	5
Mai	40	51	27	1.9	14
Juni	46	60	39	1.5	10
Mittel	23	40	14	2.9	66

Zur Bildung der Mittelwerte, wie sie in Spalte 2 für die einzelnen Monate angegeben sind, wurden nur solche Messungen verwendet die sich auf eine Ansammlungszeit von ungefähr 24 Stunden beziehen, damit ein eventueller täglicher Gang keine Fälschungen verursachen kann.

Es fällt besonders in Abb. 5. ein ausgeprägter Jahresgang auf mit einem Minimum im Jänner und einem Maximum im Sommer. Augenscheinlich besteht also eine Symbasie zwischen Exhalations- und Temperaturgang, welcher weiter unten besprochen werden soll.

Der weitere Verlauf der Jahreskurve müsste durch eine eigene Untersuchung festgestellt werden. Zu vermuten ist, dass im Juli noch ein kleiner Anstieg erfolgt, da ja auch die Temperatur noch steigt. Entsprechend wäre zu erwarten, dass von August an die Exhalation absinkt, um im Dezember wieder den niedrigen Winterwert zu erreichen, wie die Abbildung durch die punktierte Kurve andeutet, während der ausgezogene Teil den beobachteten Monatsmitteln entspricht.

Auffallend ist der tiefe Einschnitt in der Kurve beim Jännerwert, während im Dezember und Februar das Exhalationsmittel noch relativ hoch liegt. Der Vorwinter war 1932 ziemlich mild und der Boden nur selten gefroren. Im Jänner aber fror der Boden tief und fest ein, während im Februar tagsüber bereits einige Male Tauwetter einsezte. Das starke Absinken lässt sich also durch das Gefrieren des Bodens erklären.

(*b*) *Jahresmittel*—Das Mittel aus den angeführten Monaten ergibt sich zu 23×10^{-18} curie/qcm sec. Das Jahresmittel wird etwas höher anzusetzen sein, weil noch die Sommer- und Herbstmonate mit hohen Werten hinzukommen. Schätzungsweise dürfte es etwa zwischen 25

und 30×10^{-18} liegen. L. B. Smyth fand in Dublin für q den Wert von 73.3×10^{-18} curie/qcm sec, ungefähr das Dreifache unseres Betrages, während J. R. Wright und O. F. Smith in Manila in den Sommermonaten bloss ein Mittel von 20.5×10^{-18} curie/qcm sec fanden, die Hälfte unseres Sommerwertes. Die Grössenordnung stimmt aber schön überein und da die Exhalation von Ort zu Ort Schwankungen unterworfen ist, darf das Ergebnis dieses Vergleiches als gute Ubereinstimmung bezeichnet werden.

(*c*) *Extremwerte und Schwankung*—Interessante Einblicke gewähren die nächsten Spalten der Tabelle 2. In Spalte 3 ist der grösste Wert des betreffenden Monats angegeben, in Spalte 4 der kleinste. Man sieht, dass sehr grosse Unterschiede auftreten können. Ein Mass für die Grösse der Schwankung bietet Spalte 5. Auch die Grösse der Schwankung ändert sich mit der Jahreszeit: Sie war gross in Dezember, etwas kleiner im Jänner, sehr gross im Februar und nahm dann in den folgenden Monaten ab. Auch das weist wieder darauf hin, dass die Exhalation sehr stark von den meteorologischen Faktoren abhängig ist. Denn gerade in den Uebergangszeiten, beim Einbruch des Winters und beim Ausgang desselben, sind die Witterungsverhältnisse am unausgeglichensten und selber grossen Schwankungen ausgesetzt und zu diesen Perioden erscheinen auch die grössten Schwankungen in der Exhalation.

Das Verhältnis zwischen kleinstem und grösstem Jahreswert, zwischen q (min) des Jänner und q (max) des Juni ergibt ziemlich genau das Verhältnis von 1:100. In so weiten Grenzen kann sich die Exhalation innerhalb des Jahres bewegen, während man bisher nur eine Schwankung etwa in Verhältnis von 1:5 annahm[10].

(2) *Abhängigkeit von meteorologischen Faktoren*

(*a*) *von der Bodentemperatur*—

TABELLE 3

Mittlere Bodentemperaturen in Celsiusgraden	Mittlere Exhalation in 10^{-18} curie/qcm sec	Anzahl der Messungen
0 bis 3	16	8
3 " 6	18	9
6 " 9	29	11
9 " 12	42	9
12 " 15	47	10
8 bis 9	29	2
9 " 10	35	2
10 " 11	39	3
11 " 12	40	2
12 " 13	45	1
13 " 14	56	2

Zur Messung der Bodentemperatur diente ein Thermometer, das neben dem Sammelgefäss 5 cm tief in die Erde eingesteckt wurde; die Temperaturen wurden morgens, mittags und abends abgelesen und aus ihnen das Tagesmittel gebildet. In der Tabelle 3 kommt deutlich die Abhängigkeit der Exhalation von der Bodentemperatur zum Ausdruck,

[10]V. F. Hess, Die elektrische Leitfähigkeit der Atmosphäre und ihre Ursachen, Vieweg 1926, S. 75.

besonders in deren zweiten Teil, in welchem nur Messungen verwertet sind, die sich auf eine Ansammlungszeit von 17 bis 7 Uhr beziehen und die bei steigendem Luftdruck erhalten wurden. In der Nacht sind die meteorologischen Verhältnisse mehr ausgeglichen; durch die Auswahl von Messungen nur bei steigendem Luftdruck war die direkte Saugwirkung von Luftdruckdepressionen von vornherein ausgeschaltet und darum konnte die Temperaturabhängigkeit so deutlich in Erscheinung treten. E. Schmid[11] gibt in seiner Untersuchung über den Emanationsgehalt der Freiluft als wahrscheinlichen Grund für diesen Effekt an, dass mit zunehmender Erwärmung die Bodendurchnässung ab- und damit die Bodenatmung zunehme. Da bei unserer Anordnung die Bodenfeuchtigkeit fast konstant blieb, muss ein anderer Grund vorhanden sein. Wenn sich der Boden erwärmt, bilden sich vielleicht ganz feine Risse in der Erde und es könnte dadurch okkludierte Emanation den Weg in die Freiluft finden. Etwas emanationsreiche Bodenluft wird auch infolge ihrer Ausdehnung aus den Kapillaren des Untergrundes in das Sammelgefäss dringen. Vor allem dürfte aber in Betracht kommen, dass die bodennahe Luft infolge Eewärmung auf- und daher die dichtere Bodenluft nachströmt.

Die Besonnung des Bodens ruft den gleichen Effekt hervor. Ihr Einfluss vermischt sich bei unserer Methode mit dem allgemeinen der Temperatur: Die Ergebnisse waren von der Temperaturhöhe, nicht aber von der direkten Bestrahlung durch die Sonne abhängig.

(b) *von der absoluten Grösse des Luftdruckes*—

TABELLE 4

Mittlerer Luftdruck in mm Hg	Mittlere Exhalation 10^{-18} curie/qcm sec	Anzahl der Messungen	davon Märzwerte
704 bis 706	32	3	0
706 " 708	43	6	1
708 " 710	38	12	3
710 " 712	35	9	1
712 " 714	23	10	5
714 " 716	22	8	4
716 " 718	15	1	1
718 " 720	19	4	4

Ein engerer Zusammenhang zwischen Exhalation und Luftdruckmittel, das während der Ansammlungszeit herrschte, lässt sich nicht erwarten, da es nur auf eine Aenderung desselben ankommen kann. Wenn trotzdem laut Tabelle bei höherem Luftdruck die Exhalation kleiner wird, so dürfte dies davon herrühren, dass die hohen Barometerstände gerade in den März fielen, dessen tiefe Temperaturen die niedrige Exhalation bewirkten. Davon überzeugte auch eine eingehendere Untersuchung, bei der Exhalation und Luftdruck nur von jenen Tagen verglichen wurden, an denen die Bodentemperatur ungefähr die gleiche war.

(c) *von der Luftdruckschwankung*—Ein grosser Einfluss auf die Exhalation wurde von der Luftdruckänderung erwartet; denn bei

[11]E. Schmid, Met. Zs., **5**, 182 (1931); in der Fussnote die weitere zahlreiche Literatur.

6

fallendem Luftdruck muss emanationsreiche Bodenluft aus dem Untergrunde ausströmen, die Exhalation also grösser werden. Steigt das Barometer aber, so wird dieser Effekt ausbleiben und die Exhalation daher kleiner werden.

TABELLE 5

$\triangle p$ in mm Hg	Mittlere Exhalation 10^{-18} curie/qcm sec	Anzahl der Messungen
$\triangle p > 0$	24	9
0 bis -1	24	12
-1 " -2	36	12
-2 " -3	36	11
-3 " -4	32	3
$\triangle p < -4$	33	2

$\triangle p$ das Mass für die Luftdruckänderung, ist der Unterschied zwischen einem höchsten und darauffolgenden kleinsten Wert des Barometerstandes während der Sammelzeit, wie er sich bei Untersuchung des Barogrammes ergab. Das Vorzeichen ist bei abnehmendem Luftdruck negativ; ein positives Vorzeichen für $\triangle p$ sagt aus, dass das Barometer während der ganzen Ansammlungsdauer nicht gefallen ist. Der Einfluss des normalen täglichen Ganges des Luftdruckes kommt bei unseren Messungen nicht zum Ausdruck, da die Ansammlungszeiten sich über ungefähr 24 Stunden erstreckten.

Nach Tabelle 5 ist bei fallendem Luftdruck die Exhalation tatsächlich grösser als bei steigendem. Wenn das Fallen mehr als 1 mm Hg ausmacht, wird die Exhalation bedeutend grösser, sonst aber scheint die Stärke der Aenderung keine grössere Wirkung auszuüben. Exhalationswerte bei starkem Druckfall stehen aber nur in geringer Zahl zur Verfügung, sodass man keine sicheren Schlüsse ziehen kann. Dass der Einfluss der Druckänderung jedenfalls geringer ist als erwartet wurde, geht deutlich aus Tabelle 6 hervor, worin $\triangle p$ wieder die maximale Druckschwankung während der Ansammlungszeit bedeutet. Um den Temperatureffekt zu beseitigen, wurden hier nur solche Werte genommen, bei denen sich die Bodentemperatur zwischen 6° und 9° bewegte. In diesem Intervall kommen auch grössere Luftdruckschwankungen vor und es müsste daher eine Einwirkung der Luftdruckänderung hier am ehesten merkbar sein. Die Tabelle zeigt aber, dass die Verknüpfung nicht sehr stramm ist. Man muss daher zum Schlusse kommen, dass der Einfluss der Luftdruckschwankung nicht allzugross ist und dass er von anderen Faktoren leicht überdeckt wird.

TABELLE 6

$\triangle p$ in mm Hg	-8.9	-3.3	-2.1	-2.0	-1.6	-1.5	-0.8	-0.4	-0.1	$+5.4$	$+6.3$
Exhalation 10^{-18} curie/qcm sec	38	19	26	26	30	23	27	28	32	30	48

(d) *von der Luftfeuchtigkeit*—

<p style="text-align:center">TABELLE 7</p>

Dampfdruck in mm Hg	Mittlere Exhalation 10^{-18} curie/qcm sec	Anzahl der Messungen	davon März-Aprilwerte
2 bis 3	14	1	1
3 " 4	24	6	6
4 " 5	24	7	7
5 " 6	31	5	3
6 " 7	37	8	0
7 " 8	45	5	0
8 " 9	45	6	0
9 " 10	50	3	0

Nach dieser Zusammenstellung scheint bei grösserer absoluter Feuchtigkeit der Luft auch die Exhalation grösser zu werden. Diese Erscheinung kommt auch dann zum Ausdruck, wenn man nur die ersten oder letzten vier Zeilen für sich betrachtet und damit den Temperatureffekt berücksichtigt, da in den ersten Zeilen die März-Aprilwerte, in den letzten die Mai-Juniwerte erscheinen. Eine stichhältige Erklärung für diesen Effekt steht nicht zur Verfügung und bevor er nicht in einer eigenen Untersuchung gesichert ist, darf wohl daran gezweifelt werden, ob er reell ist.

Zwischen relativer Luftfeuchtigkeit und Exhalation konnte kein Zusammenhang gefunden werden.

(3) *Abhängigkeit von der Bodenbeschaffenheit*

(a) *von der Bodenfeuchtigkeit*—Regen- und Schmelzwasser konnten bei unserer gewöhnlichen Anordnung nur von der Seite her den Boden durchfeuchten unter dem Sammelgefäss, wovon die Oberfläche aber nur wenig berührt wurde. Um die Exhalation auch bei feuchtem Boden untersuchen zu können, wurde das Gefäss einige Male von seinem Platze entfernt und nach dem Regen wieder aufgestellt und nach einiger Zeit die angesammelte Emanationsmenge und damit die Exhalation bestimmt. Beim Vergleich mit dem Mittelwerte, der dem Platze und der Bodentemperatur entsprach, konnte ein Sinken der Exhalation auch nach starkem Regen nicht festgestellt werden, aber ein leichtes Ansteigen. In Tabelle 8 ist die Exhalation nach Regen mit dem Mittelwert verglichen, der demselben Platze bei derselben Bodentemperatur und der gleichen Ansammlungszeit entspricht.

<p style="text-align:center">TABELLE 8</p>

Exhalation nach Regen in 10^{-18} curie/qcm sec	56	51	37
Entsprechender Mittelwert in 10^{-18} curie/qcm sec	55	44	35

Die Bodenkapillaren waren also jedenfalls nicht mit Wasser verstopft, sondern es war eher der Boden gelockert und die Emanationsabgabe erleichtert worden. Es gibt übrigens Materialien, die in feuchtem

Zustande mehr Emanation abgeben als in trockenem und diese Erscheinung wird bei manchen Heilpräparaten verwendet. Während des Regens verstopft das Wasser die Kapillaren und hindert dadurch die Bodenatmung; so ist es erklärlich, dass bei nassem Boden ein kleinerer Emanationsgehalt der Freiluft gefunden wurde[11].

(b) *Exhalation bei gefrorenem Boden* — Wenn der Boden mit Schnee bedekt ist, verschwindet mit der Bodenatmung auch die Exhalation. Aber auch bei schneefreiem gefrorenen Boden sinkt die Exhalation auf ihren kleinsten Betrag, wie der kleine Wert in Jänner zeigt, wo eine mittlere Bodentemperatur von -10^0 C herrschte. Das Frieren der Erde hindert also die Bodenatmung überaus stark. Im Erdboden ist ja immer Wasser vorhanden, das beim Gefrieren die Kapillaren verschliesst. Interessant ist der Einfluss des Tauwetters. An drei aufeinanderfolgenden Tagen ergab sich q zu 0.6 und 1.6×10^{-18} am ersten bzw. am dritten Tag, während am zweiten die Exhalation einen Betrag von 8.0×10^{-18} curie qcm sec erreichte. Diese auffallende Vergrösserung hatte ihre Ursache darin, dass an diesem Tage für kurze Zeit Tauwetter eingetreten war. In der Übergangszeit, wo das Thermometer im Boden noch -1° C zeigte, tagsüber der Boden aber oberflächlich schon auftaute, stieg q auf einen Mittelwert von 11×10^{-18} curie/qcm sec (9 Messungen).

(4) *Täglicher Gang*

Um die Exhalation auch für verschiedene Tageszeiten zu bestimmen, wurde dem Sammelgefässe morgens und abends, öfters auch am Mittag eine Luftprobe entnommen.

TABELLE 9

Monat	Exhalation, q, 10^{-18} curie/qcm sec			$q(d)/q(n)$	Anzahl der Messungen
	am Tage $q(d)$	bei Nacht $q(n)$	Mittel über 24 Stunden		
April	39	16	22	2.5	6
Mai	48	36	40	1.3	7
Juni	51	44	47	1.2	7
Mittel	46	32	37	1.4	20

Unter Tag ist die Zeit von 8 bis 17 Uhr, unter Nacht die Zeit von 17 bis 8 Uhr verstanden. Die Tagesexhalation ist durchwegs grösser als die bei Nacht und das Verhältnis zwischen beiden ändert sich mit der Jahreszeit. Es nimmt gegen den Sommer hin ab, wie auch der Temperaturunterschied zwischen Tag und Nacht in dieser Zeit abnimmt.

TABELLE 10

Exhalation, q, 10^{-18} curie/qcm sec			$q(p)/q(a)$	Anzahl der Messungen
am Vormittag $q(a)$	am Nachmittag $q(p)$	Mittel über 24 Stunden		
49	55	47	1.1	12

Im Durchschnitt ist die Exhalation am Nachmittag, d. i. von 12 bis 17 Uhr grösser als am Vormittag, von 7 bis 12 Uhr, doch liegt das Verhältnis der beiden Grössen nahe bei eins. Unter den 12 Messungen kommen vier vor, bei denen dieser Quotient kleiner als eins ist, wo also die Exhalation am Vormittag grösser war. Das ist wohl ein Zeichen dafür, dass das Maximum in die Mittagszeit fällt, etwa in den Zeitraum von 12 bis 14 Uhr. Auch im täglichen Gang ist somit wie im jährlichen der Parallelismus mit dem Temperaturgang ausgeprägt. Der Emanationsgehalt der Freiluft zeigt einen entgegengesetzten Gang, ist also nicht so sehr von der Exhalation als vielmehr von der Durchmischung der Luft abhängig.

(5) *Vergleichsmessung in Hötting*

Da im Hofe des Institutes bei der Erbauung desselben (1904) sicher mancherlei bodenfremdes Material wie Ziegelschutt u. dgl. abgelagert wurde, war es geboten nachzuprüfen, ob an einem anderen Platze, der in seiner ganzen Ursprünglichkeit erhalten geblieben war, die Exhalation wesentlich verschieden sei. Ein solcher Ort stand in einer Gartenwiese zu Hötting, Riedgasse 9, an der Peripherie der Ortschaft zur Verfügung. Als Mittel ergab sich für die Exhalation 35×10^{-18} curie/qcm sec (10 Messungen), ein Betrag, der dem Mittel von 45×10^{-18}, das für denselben Monat dem gewöhnlichen Versuchsplatze zukommt, gut entspricht; denn gerade in dieser Zeit (Juli) fielen einige kühlere Tage und auf Rasenboden ist die Exhalation überhaupt etwas geringer, wie Messungen in unmittelbarer Nähe des ersten Versuchsplatzes zeigten. Ein Vergleich zwischen Nacht- und Tagwert ergab damals das relativ hohe Verhältnis von 1:2.7.

Das Exhalationsmittel, das nach J. Priebsch theoretisch zu erwarten ist, soll 20×10^{-18} curie qcm sec betragen unter plausiblen Annahmen über die Austauschverhältnisse zwischen den einzelnen Luftschichten und der Voraussetzung, dass der Radongehalt der Luft in 1 m Höhe über dem Erdboden 130×10^{-18} curie ccm ist. Messungen des Radiumemanationsgehaltes der Freiluft wurden in Innsbruck schon einige Male vorgenommen. R. Zlatarovic[12] erhielt 1920 ein Mittel von 433×10^{-18} und W. Illing[13] im Jahre 1933 fast denselben Wert 436×10^{-18} curie ccm, also das 3.3 fache der Menge, welche als Grundlage der obengenannten Berechnung diente. Die Exhalation sollte sich demnach bei einem so grossen, mittleren Radongehalt der Freiluft zu ungefähr 60×10^{-18} curie qcm sec ergeben. Unser experimentell gefundener Wert ist somit zu klein und reicht nur in seinen Maximalwerten an die geforderte Grösse heran. Besser wird das Verhältnis allerdings, wenn man die Bestimmung des Radongehaltes durch J. Priebsch[14] zugrunde legt, der im Jahre 1932 ein Mittel von 180×10^{-18} curie/ccm fand. Jedenfalls stimmt die Grössenordnung gut überein und mehr dürfen wir nicht erwarten, denn dazu wäre es notwendig, dass der Radongehalt der Freiluft parallel mit der Exhalation, d. h. unter gleichen jahreszeitlichen und sonstigen Verhältnissen gemessen würde. Es ist jedenfalls grössenordnungsmässig aufs Neue gezeigt, dass der Radongehalt der Freiluft durch die Nachlieferung aus dem Erdboden aufrecht erhalten wird. Es ist übrigens zu bemerken, dass es nicht schwer wäre, durch geeignete Wahl der bei

[12]R. Zlatarovic, Wiener Ber., **129**, 59 (1920).
[13]W. Illing, Dissert., Innsbruck, 1933.
[14]Nach bisher nicht veröffentlichten Messungen.

der Berechnung verwendeten, einer direkten Messung schwer zugänglichen Austauschgrössen eine bessere Übereinstimmung der berechneten und beobachteten Exhalationswerte bei gegebenem Radongehalt der Freiluft zu erzielen.

Schliesslich sei es mir erlaubt, meinem verehrten Lehrer, Herrn Professor Victor F. Hess, Vorstand des Institutes für Strahlenforschung, für die Anregungen und vielfachen Ratschläge aufrichtigst zu danken, mit denen er meine Arbeit ermöglicht und gefördert hat. Verbindlichst danken möchte ich auch Herrn Dr. Rudolf Steinmaurer für seine stete Hilfsbereitschaft und Herrn Professor Artur Wagner für die Freundlichkeit, mir die meteorologischen Daten zur Verfügung zu stellen.

MEASUREMENTS OF TOTAL NUCLEI, OF UNCHARGED NUCLEI, AND OF LARGE IONS IN THE FREE AT-MOSPHERE AT WASHINGTON, D. C.

By O. W. Torreson and G. R. Wait

Abstract—In July and August, 1931, observations were made on the total and uncharged condensation-nuclei in the free atmosphere on the grounds of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, in northwest Washington. The nuclei were measured before and after passing through a large-ion counter between the tubes of which sufficient potential was applied (about 900 volts) to remove all charged nuclei with mobility of $1/3000$ cm per second per volt per cm. From 21 sets of measurements, the ratio of uncharged to total nuclei (N_0/N_A) is found (after applying corrections for loss of nuclei while passing through the apparatus) to be 0.66, the mean value of N_0 being 6,300 and the computed value of N_A being 9,500. With potentials of 535, 890, and 1890 volts interchanged on the large-ion tubes, practically no change occurred in N_0/N_A, showing the mobility of the large ion to be not less than $1/1700$ cm per second per volt per cm.

In October and November, 1931, 77 measurements were made with the large-ion counter on the number of electronic charges of one sign (positive and negative alternately) per cc in the atmosphere, simultaneously with measurements of total and uncharged nuclei. Small ions were removed from the air entering the large-ion counter by a small-ion counter attached to the intake. From these data N_0/N_A is 0.72, $N_\pm/N_A$ is 0.14, $N_0/N_\pm$ is 5.8 and the charge per large ion 1.10, the last figure being in good support of the generally accepted view that each large ion carries only one electronic charge. It is seen that $N_A = N_0 + 2N_\pm$. The values of N_0 and N_A are more than double those found in July and August, being 15,000 and 21,000 nuclei per cc, respectively. These results are compared with the work of J. J. and P. J. Nolan, Scholz, Hess, and Israël, and evidence is found for believing that the ratio N_0/N_A increases in magnitude with increasing nuclei-content of the air.

A quite different analysis of the data obtained in October and November than was made for the above results is undertaken on the basis that $N_\pm/N_A$ is not 0.14 but has instead two values, since 23 individual values fall closely around 0.20 and the remaining 54 around 0.10. The immediate conclusion is that the nuclei are at times doubly charged. From this point of view, the data are retabulated and re-examined and it is found that the results do not show any inconsistencies which would preclude the possibility that doubly-charged large ions were present almost exclusively on certain occasions and singly-charged ones almost exclusive on other occasions during the observations here discussed.

Description of Apparatus

In March, 1931, preparations were begun by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for the investigation, at Washington, of the effects of certain elements of atmospheric pollution on the electrical condition of the atmosphere. As part of the program, plans were made for simultaneous observations on the numbers of small ions, of large ions, and of condensation-nuclei in the free atmosphere on the grounds of the Department. It was further planned to parallel these, as occasion permitted, with measurements of conductivity and rate of production of small ions.

For the measurement of the number of small ions, an ion-counter of the Ebert type, with modifications as suggested by Swann, was available. Also, for the measurement of the number of condensation-

nuclei, two Aitken nuclei-counters were available (Department numbers 6 and 7). The latter, purchased from Gustav Schulze of Potsdam, embody various changes in design by Professor Lüdeling of Berlin. Each of the counters was modified after receipt, by lengthening the piston sufficiently to completely fill the piston-chamber when the piston was placed at its highest position. Constants for these counters were determined in accordance with suggestions made in 1929 by Wait[1], and the results have been published in a recent paper[2]. The experiments, in addition to determining the correct constants for the instruments, showed that it is necessary to include in the nuclei-count the particles falling on all expansions during an observation and not only those falling on the first expansion, in order to correctly determine the number of nuclei present per unit volume in the free atmosphere. This had been the procedure of the Department in all past observations of nuclei, and was also followed throughout the measurements which are to be discussed in this paper.
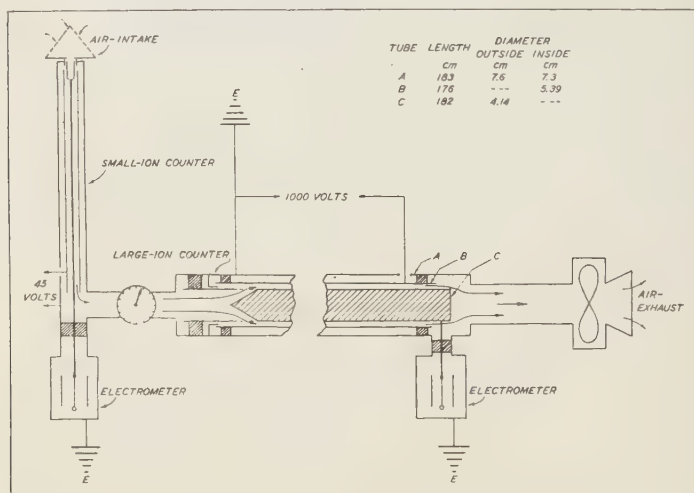
Fig. 1

As no large-ion counter was available, some time was spent in designing and constructing a suitable apparatus. The essential features of the completed counter are shown in Figure 1, which is reproduced from an earlier publication.[3] In this view, the large-ion counter is shown connected to the small-ion apparatus. Air is drawn in through a screen cap on the small-ion counter, by a turbine-fan driven by a synchronous motor, and passes first between the central and intermediate cylinders of the small-ion counter, then through an air-meter which measures the volume of air passed through, and then between the central and inter-

[1] G. R. Wait, Carnegie Inst., Year Book, No. 28, 268-269 (1928-1929).

[2] G. R. Wait, Beitr. Geophysik, **37**, 429-439 (1932).

[3] G. R. Wait and O. W. Torreson, Pub. Nation. Res. Council, Trans. Amer. Geophys. Union, 13th Annual Meeting, 182-187 (1932).

mediate cylinders of the large-ion counter. The intake-cap used during the observations to be presented here, was made of screen having 40 meshes per cm, but it was replaced for later work by a screen having 6 meshes per cm, as the fine mesh was found to act as a filter for the small ions, resulting in small-ion numbers much too small. It will be noted in Figure 1 that the exhaust fan is separated from the large-ion counter by a length of tubing of diameter approximating that of the outer tube of the counter. This tubing, 20 cm long, was inserted to minimize any turbulence created by the fan which might extend back into the large-ion counter to interrupt the stream-lines of air-flow. A Lutz single-fiber electrometer is used with each counter, arranged as shown. The heavily shaded portions of the diagram represent amber-insulators. Amber is used for all insulators excepting those supporting the inter-mediate cylinder of the small-ion counter, which are of bakelite (the latter are not shown, nor is the amber which supports the upper end of the central cylinder of the small-ion counter). The intake-end of the central cylinder of the large-ion counter is provided with a conical cap, placed about 10 cm in from the end, which deflects the air through holes in the wall of the cylinder and causes it to pass between the central and intermediate cylinders, the surfaces of which are 0.6 cm apart.

The two ion-counters, the electrometers, and the radio "B" batteries for plate-potentials for the electrometers, are mounted on a platform 30 cm wide and 2.7 meters long, the whole assembly being installed in a frame building 2.5 meters wide, 3 meters long, 2.8 meters high at the eaves, and 4.5 meters high at the ridge of the gable roof. Figure 2 is a view of the south face of the building, and the mounted apparatus can

Fig. 2

be seen through the open door. Behind the louvred window above the door is located the intake of the apparatus. The motor and exhaust-fan are mounted on a shelf on the north wall of the building instead of on the instrument-platform in order to reduce the effect on the electrometer fibers of the vibrations produced by the fan and motor. In addition, the fan and motor are connected to the ion-counters by a flexible coupling which also prevents transmission of vibrations to the instruments. The instrument-platform is mounted on four heavy wooden piers set directly into the ground and not touching the floor of the building, so that vibrations of the building cannot be communicated to the apparatus. Directly beneath the platform is located a screen-covered wooden cabinet which provides electrical shielding for the batteries that supply potential between the cylinders of the large-ion counter. On a convenient shelf nearby are located the batteries which supply the potential between the cylinders of the small-ion counter.

In order to obtain measurements of the number of condensation-nuclei remaining in the air after passing through the small- and large-ion counters, a hole 0.6 cm in diameter was made in the wall of the air-flow tube near the exhaust-end of the apparatus. A special nozzle, to fit this hole, was provided on each of the nuclei-counters. The nozzle is conical, 0.3 cm in diameter at the tip, 0.9 cm at the base, 1.7 cm long with 0.1-cm bore, and is attached at the inlet of the expansion-chamber which is controlled by the three-way valve. When taking a sample, the nozzle projects about 0.8 cm into the hole in the ion-counting apparatus. When no sample is being taken the hole is covered by a heavy rubber band which encircles the tube.

The building in which the apparatus is installed is located in the center of the site of the Department. Buildings and trees surround the location at distances varying from 15 to 30 meters according to direction, and stand from 4 to 8 meters higher than the intake of the apparatus. The site, in northwest Washington, occupies a small knoll, some 30 meters higher than the general level in the immediate vicinity. At a distance of 750 meters, however, the ground, sloping upward in all directions, reaches an elevation equal to that of the site. Along the western boundary and at the foot of the knoll, a public highway passes which affords entry to an extensive area known as Rock Creek Park, lying to the south and east. To the north and west, large residential sections approach to the edge of the site, while in all other directions heavily wooded areas intervene for a mile or two between the laboratory and other residential sections. Industrial activity on a small scale is found to the southward, about six miles away.

Winds from the northwest and west predominate in the region, though south and southeast winds occur with considerable frequency. The wind-velocity rarely exceeds 7 meters per second, and is most frequently less than 4 meters per second. Homes in the vicinity of the laboratory are heated during the interval from October to April, and the pollution in the atmosphere is undoubtedly greatest during this season of the year. The air is frequently noticeably smoky during these months.

After installation of the apparatus, a protracted period of adjustment was necessary, as the large-ion counter was made to function satisfactorily only after a long period of erratic behavior. It was necessary before adjustment of the apparatus could be begun, to determine the mag-

nitude of the potential required between the central and intermediate cyliners of the counter for the capturing of all ions having a mobility equal to or greater than 0.00033 cm per sec per volt per cm. This was derived, ignoring the effect of turbulence, from the equation $V = W/4\pi Ck$, where k is the mobility, W is the volume of air-flow in cc per sec, C is the effective capacity in cm of the apparatus, and V is the required potential in volts. Measurement of the capacity of the whole apparatus, including electrometer, on June 10, 1931, gave a value of 360 cm, which was verified on October 10, 1931, when the value 359 cm was obtained. The capacity computed from dimensions of the air-flow tubes alone, gave 330 cm and it was decided that 345 cm (the mean of the observed and computed values) would be taken as the capacity of that part of the apparatus exposed to the air-flow. Repeated observations with the air-meter showed the air-flow to be constant on all occasions at 1300 cc per sec. With these constants available, calculations showed that a potential of about 900 volts was required on the large-ion apparatus.

During June, July, August, and part of September, 1931, whenever tests were made with approximately 900 volts between the intermediate and central cylinders (in practice the 900 volts are applied between the intermediate cylinder and the earthed outer cylinder, while the insulated central cylinder is permitted to charge up only to a potential of one or two volts), and with the electrometer adjusted to a sensitivity of about 10 volts for full-scale deflection, the electrometer-fiber was found to drift out of view, sometimes in a fraction of a second, sometimes in a few seconds, but always too rapidly to be due to accumulation of charge as a result only of collection of large ions. Insulation-leaks were suspected at every possible point on one occasion or another, coronal discharges were blamed, defects in design were considered responsible and various structural modifications made from time to time, potentials were thought to be fluctuating and batteries were replaced, but the final elimination of the difficulty was brought about in such an indefinite way that the real cause of the trouble cannot be definitely stated. However, it is believed that, among the several manipulations performed just before the counter began to function satisfactorily, the polishing of the outer surface of the central cylinder with very fine emery-cloth was probably the most efficacious in correcting the difficulty. This was done on September 19, 1931, and the apparatus has functioned satisfactorily since that time, with, however, repetition of the polishing process every month or two to remove accumulation of dust and soot. Warning of the need for cleaning is given from time to time by frequent flicking of the fiber during observations, due no doubt to momentary partial discharge between the central and intermediate cylinders across the dust- or soot-particles.

Similar though less persistent difficulties were encountered when preparing the small-ion counter for operation. With an effective capacity of 5 cm for the part exposed to the air-flow,[4] and the air-flow, as already stated, of 1300 cc per second through the apparatus, a potential of 45 volts between the central and intermediate cylinders would remove all ions with a mobility equal to or greater than 0.5 cm per sec per volt per cm. With such a potential applied the fiber was found to behave erratically, but repeated cleaning of insulators finally eliminated the difficulty. However, until the large-ion counter was made to operate

[4] Capacity determined by G. R. Wait in June 1933; results not yet published.

correctly, in the middle of September, 1931, the small-ion apparatus was left with all three cylinders earthed. Such was the case during the series of measurements on nuclei made in July and August which are first to be presented.

All measurements which are to be discussed were made on days of favorable weather; no observations were made on days disturbed by fog, mist, rain, or high winds, or which were overcast or threatening. Observations were begun in the morning when possible, at 9 or 10 hours 75th meridian time (west) and were continued throughout the day until 16 or 17 hours, unless meteorological conditions changed radically or in-strumental difficulties arose.

Although the large-ion counter was not functioning sufficiently well during July and August, 1931, to permit direct measurement of the number of electronic charges per cc in the atmosphere carried on large ions, it could nevertheless be used to extract ions from the air passing through it, by the application of potentials across the cylinders. It was therefore possible, by measuring the number of nuclei in the free air near the intake of the apparatus and again at the 0.6-cm aperture beyond the large-ion counter, to determine the effect on the nuclei-content of differ-ent potentials across the cylinders. Information about the mobility of the large ions could in this way be obtained.

When making such measurements with the nuclei-counter at two different places, or at the same place but with two or more voltages placed successively across the cylinders of the large-ion counter, the "counts" were alternated or rotated. Thus, if nuclei were being meas-ured at the intake and outlet of the ion-counter, one "count" at the in-take would be followed by one "count" at the outlet and this alternation continued until ten "counts" had been obtained at each place. In this way the mean of the ten "counts" at each place would have the same mean time. Each "count" consisted of the sum of all nuclei falling on all expansions in that "count." When the nuclei-counters were operating well, each "count" would require about one minute, and 20 alternated "counts" would require 20 minutes, and so on. In Table 1 are shown measurements of nuclei at the intake and outlet (the 0.6-cm aperture) of the ion-counting apparatus and other measurements at the 0.6-cm aper-ture only but with 0, 535, 980, and 1890 volts across the cylinders of the large-ion counter. For all these measurements, the small-ion counter, as mentioned above, had all cylinders earthed. The significance of these data will be discussed later.

After the middle of September, when it became possible to under-take measurements with the large-ion counter, the program of observa-tions was altered to include measurements of number of nuclei per cc of air at the intake of the ion-counting apparatus, of small-ion and large-ion content of the atmosphere or, more strictly, of the number of elec-tronic charges of one sign per cc, and of nuclei at the 0.6-cm aperture at the end of the large-ion counter. This program required the atten-tion of two observers, one confining himself to observations of nuclei, making alternate "counts" at the intake and outlet of the apparatus, the other operating the two ion-counters. As the measurements on nuclei required about 20 minutes for one set, air was passed through the ion-counters for that length of time and the volume passed through was measured for each set. The sensitivity of both electrometers was

determined for each set of observations either before or after the set, and test of insulation-leak made both before and after each set. All these factors entered into the determination of the number present of electronic charges of one sign per cc, on the average, during each 20-minute interval. Thirty-six sets of observations were obtained between October 2 and November 21, half being made on positive and half on negative large and small ions. Table 2 presents these data, with the exception of the results on the small-ion content.

The measurements of small-ion content were omitted because subsequent work showed that the values obtained were too small. This was discovered by alternating the 40-mesh screen intake-cap with a 6-mesh screen cap in a series of measurements, the small-ion count being always much greater with the larger-mesh screen. However, alternation of the two caps had no appreciable effect on the measurements with the large-ion counter, and it is evident that the small ions, with their greater mobility, were removed in appreciable numbers by an inductive effect while having to pass close to the wires of the fine-mesh cap, whereas the large ions, with their much smaller mobility, were affected little, if any.

Included in Table 2 are computations of the ratios of uncharged to total nuclei, N_0/N_A, and of electronic charges to total nuclei, N_+/N_A. It should be noted that these ratios are derived from separate sets of data which make them quite independent of one another. Computations of the number of electronic charges per large ion are also included in the Table, as well as values of the ratio of uncharged nuclei to number of electronic charges, $N_0/N_\pm$. Detailed discussions of these results will be undertaken later.

In the latter part of November, the program of observation was curtailed by omitting measurement of N_0, the number of nuclei at the 0.6-cm aperture in the apparatus.

Forty-one sets of measurements of nuclei at the intake, of large ions, and of small ions, were obtained on November 21, 23, 24, and 25, and these are summarized in Table 4, omitting, again, the small-ion results. Computations of the ratio of charged to total nuclei, N_+/N_A, are given in the table, as well as values of the electronic charge per large ion, the latter being derived on the assumption that the ratio N_0/N_A remained 0.72 for the period covered by Table 4.

DISCUSSION OF RESULTS

It is now generally believed that the so-called large ions of the atmosphere are essentially condensation-nuclei which have become charged, and that the condensation-nuclei themselves come into the air in part, at least, from domestic and industrial fires. The data which are to be presented in this discussion will be seen to support this view.

In a locality like that of Washington where there are few industrial fires but where the winter months require heating in the homes, the number of nuclei in the air will be greater in the cold than in the warm months. From Table 1 it is seen that in the mid-summer month of July, 1931, the average number of nuclei present per cc was 10,000. In October and early November, according to Table 2, the average number of nuclei had increased to 20,000 per cc, and in late November had further increased to 25,000, as shown by Table 3. A corresponding in-

TABLE 1—*Observed total and uncharged condensation-nuclei at Washington, D. C., summer 1931*

Date	75° west meridian mean time	Number of nuclei per cc of air					Ratios			
		Just before entering large-ion counter	After passing through large-ion counter with potentials on counter as indicated							
		N_A	0 volts N'_A	1890 volts $N_{0,1}$	890 volts $N_{0,2}$	535 volts $N_{0,3}$	N'_A/N_A	$N_{0,1}/N'_A$	$N_{0,2}/N'_A$	$N_{0,3}/N'_A$
	h m									
1931 July 21	16 20	7900	5800				0.74			
22	16 19	7800	9000				1.15			
23	16 28	10100*	5400*							
	10 02	5000	5100				1.02			
	10 39	6800	6500				0.95			
	11 22	7500	6200				0.83			
	11 50	9000	6700				0.75			
	12 30	6300	6300				1.00			
	14 58	9900	9000				0.97			
24	15 05	17100	15000				0.88			
	15 17	15200	11900				0.78			
	16 42	16000	17000				1.06			
	16 04	17600	15700				0.89			
	10 50	10700	10900				1.02			
	11 14	11100	10300				0.93			
	12 30	13600	11600				0.85			
	15 45	8300	7200				0.87			
	15 58	8600	8400				0.98			
	16 14	10500	9800				0.93			
30	09 54		9540	7360	7130			0.77	0.75	
	10 26		8620	7700	5400			0.89	0.63	
	10 57		8510	5290	5860			0.62	0.69	
	11 27		7590	6440	6670			0.85	0.88	
	12 16		7590	4940	4830			0.65	0.64	
	13 45		9660	8050	6670			0.83	0.69	
	14 39		9080		6900	7020			0.76	0.77
	15 08		14260		10460	11620			0.73	0.81
31	11 00		13460		9540	11040			0.71	0.80
	11 30		8970		6560	7360			0.73	0.82
	12 50		9200		7130	6780			0.78	0.74
	13 14		4190		3290				0.79	
Aug. 7	14 04		4770		2840				0.60	
	16 01		5290		3550	4770			0.67	0.90
8	10 40		6320		4260	4450			0.67	0.70
	11 06		4900		4260	3810			0.87	0.78
	11 36		7130		4370	4480			0.61	0.63
			8400		5520	6560			0.66	0.78
14	15 51		7590		5750	5860			0.76	0.77
15	11 29		14700		10920				0.74	
			13680		9780				0.71	
Means:										
18 values		10494	9611				0.92			
6 values			8585	6630				0.77		
21 values			8736		6271				0.72	
11 values			8600			6705				0.77

TABLE 2.—*Observed total nuclei, uncharged nuclei, and electronic charges per cc with computed values large-ion content, charge per large ion, and percentage nuclei charged in free air at Washington, D. C., October to November 1931 (900 volts on tubes of large-ion counter)*

Date	75° west meridian mean time (h m)	Nuclei per cc — Total N_A	Nuclei per cc — Uncharged N_0	Ratio N_0/N_A	Computed large ions one sign $(N_A-N_0)/2$	Observed $N+$	Observed $N-$	$N+/\frac{N_A-N_0}{2}$	$N-/\frac{N_A-N_0}{2}$	$N+/N_A$	$N-/N_A$	$N_0/N+$	$N_0/N-$
1931 Oct. 2	14 20	21000	13650	0.65	3675		1882		0.51		0.09		7.2
	14 48	11620	10000	0.86	810		1446		1.79		0.12		6.9
3	15 55	23000	18860	0.82	2070	2079		1.00		0.09		9.1	
	16 18	21210	18480	0.87	1365		2231		1.63		0.11		8.3
	16 09	22890	15960	0.70	3465	4993		1.42		0.22		3.2	
9	10 30	14700	8610	0.59	3045		3040		1.00		0.21		2.8
	10 54	13440	6720	0.50	3360	3140		0.93		0.23		2.1	
	11 48	11730	8860	0.76	1435		2210		1.54		0.19		4.0
	11 42	13680	11620	0.85	1030	2700		2.62		0.20		4.3	
	12 06	8860	6210	0.70	1325		1720		1.30		0.19		3.6
10	11 54	36540	24780	0.68	5880	3830		0.65		0.10		6.5	
	11 14	34230	23520	0.69	5355		3590		0.67		0.10		6.5
	11 36	29400	24570	0.84	2415	4390		1.82		0.15		5.6	
	11 59	24150	18480	0.77	2835		4470		1.58		0.19		4.1
	12 18	21420	14910	0.70	3255	4180		1.28		0.20		3.6	
	12 37	27300	18480	0.68	4410		3920		0.89		0.14		4.7
16	11 25	23520	13650	0.58	4935	2860		0.58		0.12		4.8	
	12 46	10350	7700	0.74	1325		2300		1.74		0.22		3.3
	12 16	12540	8400	0.67	2070	2250		1.09		0.18		3.7	
	12 38	15410	11380	0.74	2015		2710		1.34		0.18		4.2
	10 09	22890	11760	0.51	5565	1847		0.33		0.08		6.4	
	10 46	13230	8400	0.63	2415		1409		0.58		0.11		6.0
	10 16	16680	12540	0.75	2070	1620		0.78		0.10		7.7	
	11 42	18900	10500	0.56	4200		4049		0.96		0.21		2.6
17	14 04	13860	7140	0.52	3360	2410		0.72		0.17		3.0	
	14 18	16440	10120	0.62	3160		1870		0.59		0.11		5.4
	15 52	14910	14280	0.96	315	1810		5.75*		0.12		7.9	
	11 14	22680	15750	0.69	3465	2280		0.66		0.10		6.9	
	11 08	20160	14910	0.74	2625		1770		0.67		0.09		8.4
Nov. 5	11 33	27300	21420	0.78	2940	2660		0.90		0.10		8.1	
	11 15	29860	22410	0.75	3725		2680		0.72		0.09		8.4
	14 52	29650	25720	0.87	1965	2730		1.39		0.09		9.4	
	15 36	26250	24360	0.93	945		2430		2.57		0.09		10.0
	15 20	28240	17490	0.62	5375	2270		0.42		0.08		7.7	
21	10 47	32020	20480	0.64	5770		2440		0.42		0.08		8.4
	10 48	36330	29820	0.82	3255	6140		1.89		0.17		4.9	
No. obs'ns		36	36	36	36	18	18	17	18	18	18	18	18
Means		21289	15330	0.716	2980	3010	2565	1.09	1.14	0.139	0.140	5.83	5.82

*This value not used in mean.

crease in number of large ions from October to November is also shown by Tables 2 and 3.

In the first part of Table 1, in addition to values of the number of nuclei present in the atmosphere (N_A), there are measurements of nuclei at the outlet of the apparatus with all tubes connected to Earth (N'_A). Values of N'_A and N_A were obtained simultaneously and the ratio 0.92 of N'_A N_A indicates a loss of 8 per cent of nuclei in passing through the apparatus. The matter of loss of nuclei, though important, was not pursued farther in connection with the present series of observations, and the ratio N'_A N_A is chiefly of value in placing the data in the lower part of Table 1 on a basis permitting comparison with results in later tables. Mean values of $N_{0,1}/N'_A$, $N_{0,2}/N'_A$, and $N_{0,3}/N'_A$ are shown to be 0.77, 0.72, and 0.77 respectively, and from these values the ratios $N_{0,1}/N_A$, $N_{0,2}/N_A$, and $N_{0,3}/N_A$ are computed as 0.71, 0.66, and 0.71. The value 0.66, representing $N_{0,2}/N_A$ will be referred to again, since $N_{0,2}$ was obtained with 890 volts applied to the tubes of the large-ion counter. In all subsequent observations with the large-ion apparatus, values of $N_{0,2}$ were designated N_0 since 890 volts were used throughout, and the ratio $N_{0,2}/N_A$ for Table 1 is therefore directly comparable with values of N_0/N_A found in later tables.

It is of importance to note how little difference exists between the three ratios 0.77, 0.72, and 0.77 in spite of the fact that values of $N_{0,1}$, $N_{0,2}$, and $N_{0,3}$ were obtained with 535, 890, and 1890 volts, respectively, on the tubes of the counter. From these results it must be concluded that the saturation-potential for the charged nuclei, during the period, was 535 volts or less. The mobility of the charged nuclei, or large ions, on the basis of 535 volts saturation-potential, when computed from the formula $k = W/4\pi C V$, is found to be greater than 1/1700 cm per sec per volt per cm. This value is obtained without allowance for turbulence in the air-flow through the counter; the presence of turbulence would make the computed mobility lower than the correct value. The mobility as computed is about twice as great as that usually accepted for large ions.

Turning to Table 2, additional conclusions may be drawn, owing to the expanded observational program. For all the measurements in this Table, approximately 900 volts were applied between the intermediate and other cylinders of the large-ion apparatus. Also, 45 volts were applied across the cylinders of the small-ion counter, and thus all small ions having a mobility greater than 0.5 cm per sec per volt per cm were drawn out before the air arrived at the large-ion counter.

It will be noted immediately that the ratio N_0 N_A —namely 0.72 in Table 2 is higher than the same ratio as computed from corresponding data in Table 1 —namely 0.66. That the number of uncharged nuclei probably increased with an increase in total nuclei with the change from summer to autumn, following the resumption of operation of domestic heating-plants, will be seen from what follows.

J. J. and P. J. Nolan[5] obtained the mean value 0.56 for N_0 N_A from 235 sets of observations of N_0 and N_A in the free atmosphere at Glencree, Irish Free State, from October, 1928, to December, 1930. Glencree Valley, situated 18 km south of Dublin and about 10 km from the east coast, is a sparsely inhabited region. Scholz[6] at Potsdam, Germany, in Feb-

[5] J. J. and P. J. Nolan, Proc. R. Irish Acad., A, **40**, 3-59 (1931).
[6] J. Scholz, Zs. Instrumentenk., **51**, 505-522 (1931).

ruary and March, 1931, made 12 sets of measurements of N_0 and N_A in the free atmosphere and obtained the value 0.53. It will be seen that the results of the Nolans and Scholz agree closely, but they do not agree with the value 0.72 given in Table 2. If, however, the extensive results of J. J. and P. J. Nolan are examined, it becomes immediately evident that with a north wind the condensation-nuclei were brought down from Dublin in greater numbers than were found with the winds from other quarters, and from 19 sets of observations obtained during north winds, the mean of the individual values of the ratio N_0, N_A is found to be 0.69. The average values of N_A and N_0 are 12,380 and 9,225 nuclei per cc, respectively, based on only the first expansion of the nuclei-count instead of all expansions. According to Wait[2], these values are only 63 per cent of what would have been obtained from all expansions. To make them comparable with the nuclei-counts presented in this paper, the values must be increased to 19,650 and 14,640 per cc. Again, taking 6 sets of observations made during northeast winds, the mean of the six individual ratios of N_0/N_A is found to be 0.70 while N_A and N_0 have the values 7,235 and 5,435, respectively. The latter values, adjusted on the basis of all expansions, become 11,480 and 8,620. During east winds, 15 sets of observations gave 5,390 for N_A and 2,960 for N_0, with a mean ratio of 0.58. The adjusted values here become 8,560 for N_A and 4,700 for N_0. The remaining 195 individual ratios obtained for all other wind-directions and for calm give the mean value of 0.54 and 1,360 and 760 as the mean values of N_A and N_0, which, when adjusted, become 2,160 and 1,210.

Israël, at Frankfort in May, 1929,[7] made a series of observations which are of interest at this point, although values of N_0 were not directly obtained. From 30 sets of measurements of N_A, N_+, and N_- in outdoor air he found the mean value of $(N_+ + N_-)/N_A$ to be 0.17. On the assumption that $(N_0 + N_+ + N_-) = N_A$, the ratio N_0 N_A becomes 0.83. The mean value of N_A for the 30 sets was 63,560 nuclei per cc. If, now, the values of N_A are tabulated for the different observers, together with the corresponding values of N_0 N_A, the results given in Table 3 follow.[a]

TABLE 3—*Variation in ratio of uncharged to total nuclei with change in total nuclei*

Observers	Place and date	No. sets	N_A	N_0/N_A
J. J. and P. J. Nolan	Glencree, 1928-30	195	2160	0.54
J. J. and P. J. Nolan	Glencree, 1928-30	15	8560	0.58
Wait and Torreson	Washington, July-Aug. 1931	21	9500	0.66
J. J. and P. J. Nolan	Glencree, 1928-30	6	11480	0.70
J. J. and P. J. Nolan	Glencree, 1928-30	19	19650	0.69
Wait and Torreson	Washington, Oct.-Nov. 1931	36	21290	0.72
Israël	Frankfort, 1929	30	63560	0.83
Scholz	Potsdam, 1931	12	77360	0.53

[7]H. Israël, Beitr. Geophysik, **23**, 144-166 (1929).

[a]Since the completion of this manuscript, the results of C. O'Brolchain at Graz (Beitr. Geophysik, **38**, 4-15, 1933) and of P. F. Schachl at Innsbruck (Beitr. Geophysik, **38**, 202-219, 1933) have come to the attention of the authors. The results of O'Brolchain and Schachl when compared with those in Table 3, above, show no agreement.

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From inspection of this table it appears not improbable that the ratio of uncharged to total nuclei in the atmosphere bears some relation to the number of nuclei present. The lack of agreement with this suggestion in the case of the results obtained by Scholz, however, cannot be disregarded.

Various determinations have been made of the value of the ratio of uncharged nuclei to charged nuclei of one sign, $N_0/N_{\pm}$. In many cases, however, either N_0 or $N_{\pm}$ has been indirectly determined from the equation $(N_0 + 2N_{\pm}) = N_A$. The resulting ratios cannot, in such cases, be regarded as completely satisfactory, for without simultaneous observation of N_A, N_0, and $N_{\pm}$, it is impossible to know whether the charged nuclei, on a given occasion, are singly- or doubly-charged and, since the ratio $N_0/N_{\pm}$ is invariably derived from observed numbers of electronic charges rather than observed numbers of charged nuclei, it will be in error whenever the charge per large ion is more than one. J. J. and P. J. Nolan from their long series of measurements of N_A and N_0 at Glencree[5] derived the value 2.2 for $N_0/N_{\pm}$, after assuming the charge per large ion to be unity, and assuming positive and negative large ions equal in number. If, however, the regrouping of observations of J. J. and P. J. Nolan as given in Table 3 is taken as the basis for determining $N_0/N_{\pm}$, its value varies from 2.2 to 4.7 for the different groups, increasing with increasing nuclei-content of the atmosphere.

Hess[3] while making an atmospheric-electric survey on the island of Helgoland in August and September, 1928, made six sets of measurements of N_A, N_+, and N_-, from which he obtained 2.24 for the ratio $N_0/N_{\pm}$, on the assumption that $N_0 = [N_A - (N_+ + N_-)]$—thereby assuming also unit charge on each large ion. Israël[7] from his 30 sets of measurements of total nuclei and electronic charges of both signs, found $N_0/N_{\pm}$ to be 10[b], after making the same assumption as Hess. In Table 2 it will be seen that $N_0/N_{\pm}$ is 5.8 for the data under discussion here, which is about the mean of the high value of 10 obtained by Israël and the value 2.24 obtained by Hess, but is only slightly higher than the 4.7 obtained from a portion of the results of J. J. and P. J. Nolan. It is perhaps surprising that the individual values of $N_0/N_{\pm}$ in Table 2 scatter so widely; they might have been expected to approach more nearly a constant value on the basis that the ratio is theoretically equal to the recombination-coefficient between small ions and charged nuclei divided by the coefficient between small ions and uncharged nuclei under equilibrium-conditions. Later in the discussion the data will be scrutinized from a different point of view than has been adopted for the discussion thus far, and it will be seen that some of the scatter may perhaps be explained.

If the equation $N_A = (N_0 + N_+ + N_-)$ is true, then all large ions are condensation-nuclei which have acquired a single electronic charge and all nuclei are capable of becoming large ions; furthermore, the number of electronic charges (positive and negative) observed with the large-ion counter will represent the number of large ions present. From Table

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[5]V. Hess, Beitr. Geophysik, 22, 256-314 (1929).

[b]Note: Israël states in his abstract and in the text of his article that $N_0/N_{\pm}$ is 6 to 7. Upon inspection of his data on page 158, it appears that N_0 refers to total nuclei for which N_A is used in this discussion. Furthermore, his value of 6 to 7 is obtained from $N_A/(N_+ + N_-)$ and not by using only N_+ or N_-. When the assumption is made that $N_0 = (N_A - N_+ - N_-)$, the ratio $N_0/N_{\pm}$ becomes 10.

2, N_0 is 15,330; N_+ is 3,010; N_- is 2,565, and their sum is 20,905. This sum compares so closely with the average for the total nuclei, $N_A = 21,289$, as to afford strong confirmation of the reality of the suggested relationship between nuclei and large ions.

As positive and negative large ions were not measured simultaneously, the values of electronic charge per large ion in Table 2 were computed on the basis that positive and negative large ions were equal in number. The ion-numbers were thus obtained from $(N_A - N_0)/2$, which were then divided into the corresponding observed numbers of electronic charges. Seventeen sets of observations on positive electronic charges gave an average value of 1.09 charges per ion, and eighteen sets on negative gave an average of 1.14. This confirms very well the belief that each large ion carries only one electronic charge. The individual values scatter considerably, of course, but it must be recognized that the computation is extremely sensitive to errors in the values of N_A and N_0. It is quite possible for these to be in error by a few per cent and in opposite directions for any simultaneous pair, and a change of 1,000 or 2,000 nuclei in any set of observations would affect any individual computed value of the electronic charge per ion enormously. In view of this fact, the scatter of the individual values is not at all unreasonable and argues favorably for the accuracy of the whole series of observations.

For computing the electronic charge per ion from observations shown in Table 4 it was necessary to assume that the ratio N_0/N_A remained 0.72 for the latter part of November as it was for October and early November. The increase in the number of nuclei in late November was not sufficiently great to require assuming a larger value of the ratio. The number of large ions of one sign could then be taken as $0.14N_A$, and the electronic charge per large ion readily derived. Twenty sets of observations on positive ions and twenty on negative gave the values of 1.10 and 1.09, respectively, for the charge per ion, which are in excellent agreement with similar results in Table 2. These results, it should be emphasized, are for the free atmosphere. The electronic charge per large ion in the free atmosphere is usually assumed to be unity, but the observations upon which such an assumption has been based have all been open to objection. Hogg[9], in Australia, who is sometimes credited with having determined the charge per large ion, found the charge per intermediate ion (mobility about 0.005 cm per sec per volt per cm) to be unity in outdoor air, but he made no determination of the charge per large ion. J. J. Nolan, Boylan, and de Sachy[10], in Irish Free State, in 1925, found the charge per large ion to be unity in air in a closed room, but they made no determination for outdoor air. Scholz[6] made observations on the charged and uncharged nuclei and large ions in the air of a basement-room at the University of Graz, and some authorities have referred to this work in discussing the charge per large ion, in the free atmosphere. In view of our limited knowledge of the relationship between large and intermediate ions, the determination of the charge per intermediate ion by Hogg cannot be said to be indicative of the number of charges carried by the large ion. Equally open to objection are the observations on the charge per large ion inside of buildings, for it is

[9] A. R. Hogg, Nature, **128**, 908 (1931).

[10] J. J. Nolan, R. K. Boylan, and G. P. de Sachy, Proc. R. Irish Acad., A, **37**, 1-12 (1925).

TABLE 4—Observed total nuclei and electronic charges per cc with computed values of charge per large ion and percentage nuclei charged in free air at Washinton, D. C., November 21-25, 1931

Date	75° west meridian mean time	Total number nuclei per cc N_A	Number electronic charges per cc		Ratios		Electronic charges per large ion	
			$N+$	$N-$	$N+/N_A$	$N-/N_A$	$0.714 \times N+/N_A$	$0.714 \times N-/N_A$
1931 Nov. 21, 23	11 24	30660		3800		0.124		0.89
	10 59	34440	9650		0.280		2.00	
	11 18	33390		9220		0.276		1.98
	11 44	21630	5530		0.255		1.83	
	12 08	26250		5240		0.200		1.43
	13 34	17850	3290		0.184		1.32	
	13 58	21000		2780		0.132		0.95
	14 24	27720	3300		0.121		0.87	
	15 27	21840		3210		0.147		1.05
	15 49	22050	3040		0.138		0.99	
	16 08	18900		2620		0.139		1.00
24	09 55	55120	8580		0.156		1.12	
	10 30	30765		7960		0.259		1.85
	10 47	35700	9190		0.257		1.84	
	11 04	27300		7870		0.288		2.06
	11 25	38430	6850		0.178		1.27	
	11 48	41480		5340		0.129		0.92
	12 07	47780	6110		0.128		0.92	
	12 28	33080		4410		0.133		0.95
	13 32	27820	3640		0.131		0.94	
	14 00	26250		2560		0.097		0.69
	15 02	17220	2040		0.118		0.84	
	15 26	37800		4130		0.109		0.78
	15 46	32550	3390		0.104		0.74	
	16 06	29920		4440		0.148		1.06
25	09 36	21420	3000		0.140		1.00	
	09 58	19740		2710		0.137		0.98
	10 20	23940	2190		0.092		0.66	
	10 46	14700		2270		0.154		1.10
	11 06	22890	3110		0.136		0.97	
	11 29	46620		3600		0.077*		0.55*
	11 46	19950	2250		0.113		0.81	
	12 06	18690		1940		0.104		0.74
	13 44	15645	2000		0.128		0.92	
	14 10	17010		1860		0.109		0.78
	14 29	17430	1930		0.111		0.79	
	14 48	21420		2240		0.104		0.74
	15 40	15750	2370		0.150		1.07	
	15 33	18480		2480		0.134		0.96
	15 53	14700	2230		0.152		1.09	
	16 12	18480		2190		0.118		0.84
No. obs'ns		41	20	21	20	20	20	20
Means		26434	4184	3946	0.154	0.152	1.10	1.09

*These values not used in means since condensation-nuclei abnormally high.

quite conceivable that changes in the number of charges per ion may take place in the open air, especially at peak-times of replenishing domestic fires or at times of concerted commencement of industrial and business activities. As a matter of fact, the data presented in Tables 2 and 4 strongly support the idea that changes may occur at frequent intervals in the number of charges carried by large ions, if those data are somewhat differently tabulated and re-examined.

When the columns of N_+/N_A and N_-/N_A in Table 2 are carefully inspected, it is found that the values appear to fall into two groups the respective means of which are about 0.10 and 0.20. In fact, there are only two values, 0.15 and 0.14, out of thirty-six, which might be considered indefinite as to grouping. Such a result suggests the possibility that during certain 20-minute periods of observation each ion carried two electronic charges. To further explore this possibility, the data in Table 2 were separated into two groups (1) and (2), according to values of $N_\pm/N_A$, as shown in Table 5.

Inspection of Table 5 shows that the average value of total nuclei, N_A, for group (1) is very much larger than for group (2). However, in both groups about 70 per cent are uncharged, while the exact figures, 0.74 for group (1) and 0.69 for group (2), are in keeping with the suggestion made earlier that the ratio of uncharged to total nuclei depends upon the number of nuclei present, being greater when the nuclei are more numerous. The average values of N_+/N_A are almost exactly 0.10 and 0.20 for groups (1) and (2) respectively, as was anticipated from inspection of Table 2.

Turning now to the application of the equation $N_A = (N_0 + N_+ + N_-)$ it is seen that in group (1) of Table 5, $N_0 = 17,529$, $N_+ = 2,580$, and $N_- = 2,334$, which total to 22,443. The latter value is, however, only 94 per cent of 24,006, the corresponding value of N_A. This result once more calls attention to the possibility that there may be a few per cent (6 to 8) of the total nuclei lost in passing through the apparatus. For group (2) $N_0 = 11,879$, $N_+ = 3,688$, and $N_- = 2,928$, giving a total of 18,495, which is in excess of the value of 17,019 for N_A by 8 per cent. Since the excess for group (2) of 8 per cent is so nearly equal to the deficiency of 6 per cent for group (1), perhaps the conclusion may be drawn that the grouping has been based merely on a fortuitous distribution of the observations and may not be warranted.

It is possible, however, that the 8 per cent excess of the average observed N_A for group (2) over the computed value, appears only because some or all of the large ions carried more than one charge. If it is assumed that *all* the large ions in group (2) were doubly-charged, the ion-numbers for N_+ and N_- become 1,844 and 1,464, respectively, and these added to 11,879 give a total of 15,187, which is only 89 per cent of 17,019. According to this assumption, therefore, 11 per cent of the nuclei appear to be lost in passing through the apparatus, which is about double the number apparently lost in the case of group (1).

Values of N_0/N_+ and N_0/N_- in Table 5 are 7.3 for data in group (1) and 3.5 for data in group (2), regardless of the sign of the large ions. The value 3.5, of course, has no significance if the large ions in that group are doubly-charged, as it represents a ratio between electronic charges and nuclei-numbers and not a ratio between large-ion numbers

TABLE 5—*Recapitulation of results in Table 2 to investigate presence of doubly-charged large ions*

Number nuclei per cc		Number electronic charges per cc		Ratios					Electronic charge per large ion	
N_A	N_0	N_+	N_-	N_+/N_A	N_-/N_A	N_0/N_A	N_0/N_+	N_0/N_-	$N_+ / \dfrac{N_A - N_0}{2}$	$N_- / \dfrac{N_A - N_0}{2}$
Group (1)—Values of $N_\pm/N_A$ less than or equal 0.15										
21000	13650		1882		0.09	0.65		7.9		0.51
11620	10000		1446		0.12	0.86		6.9	1.00	1.79
23000	18860	2079		0.09		0.82	9.1			1.63
21210	18480		2231		0.11	0.87		8.3		
36540	24780	3830		0.10		0.68	6.5		0.65	0.67
34230	23520		3590		0.10	0.69		6.5		
29400	24570	4390		0.15		0.84	5.6		1.82	0.89
24570	18480		3920		0.14	0.68		4.7		
23520	13650	2860		0.12		0.58	4.8		0.58	0.58
18480	11760	1847		0.08		0.51	6.4		0.33	
27300	8400		1409		0.11	0.63		6.0	0.78	0.59
13650	12540	1620		0.10		0.75	7.7			
23520	10120		1870		0.11	0.62		5.4	5.75*	0.67
22890	14280	1810		0.12		0.96	7.9		0.66	
11760	15750	2280		0.10		0.69	6.9			0.72
13230	14910		1770		0.09	0.74		8.4	0.90	
8400	21420	2660		0.10		0.78	8.1			2.57*
12540	22410	2730		0.09		0.75	9.4		1.39	
16680	25720		2680		0.09	0.87		8.4		0.42
16440	24360	2270		0.08		0.93	7.7		0.42	
10120	17490		2430		0.09	0.62		10.0		
14910	20480		2440		0.08	0.64		8.4		
24006 (22)	17529 (22)	2580 (11)	2334 (11)	0.103 (11)	0.103 (11)	0.735 (22)	7.3 (11)	7.3 (11)	0.85 (10)	0.85 (10)
Group (2)—Values of $N_\pm/N_A$ greater than 0.15										
22890	15960	4993		0.22		0.70	3.2		1.42	1.00
14700	8610		3040		0.21	0.59		2.8		
13440	6720	3140		0.23		0.50	2.1		0.93	1.54
11730	8860		2210		0.19	0.76		4.0		
13680	11620	2700		0.20		0.85	4.3		2.62	1.30
8860	6210		1720		0.19	0.70		3.6		1.58
24150	18480		4470		0.19	0.77		4.1		
21420	14910	4180		0.20		0.70	3.6		1.28	1.74
10350	7700		2300		0.22	0.74		3.3		
12540	8400	2250		0.18		0.67	3.7		1.09	1.34
15410	11380		2710		0.18	0.74		4.2		0.96
18900	10500		4049		0.21	0.56		2.6	0.72	
13860	7140	2410		0.17		0.52	3.0		1.89	
36330	29820	6140		0.17		0.82	4.9			
17019 (14)	11879 (14)	3688 (7)	2928 (7)	0.196 (7)	0.199 (7)	0.687 (14)	3.5 (7)	3.5 (7)	1.42 (7)	1.35 (7)

*These values not used in means.
Note: The numbers in parentheses indicate number of observations from which mean immediately above is derived.

and nuclei-numbers; the significant value is twice 3.5 or 7.0, which is very close to the value 7.3 for group (1). The values 7.0 and 7.3 lie midway between the highest value obtainable from the results of J. J. and P. J. Nolan, namely 4.7, and the value 10 obtained by Israël. The range in these values is explainable as suggested by earlier considerations, on the basis that the ratio $N_0/N_\pm$ increases with increasing nuclei-content of the atmosphere.

In the last two columns of Table 5 are grouped values of the electronic charge per large ion. The means, after omitting two extreme values, are 0.85 for both positive and negative ions in group (1), and 1.42 and 1.37 for the positive and negative, respectively, in group (2). These values can be readily adjusted to integral values of 1 and 2 on the basis that nuclei were lost in the apparatus. It is impossible, however, to adjust all these values to unity by any one method; in other words, an adjustment which can be used to increase the value 0.85 to unity cannot serve, at the same time, to decrease the values 1.37 and 1.42 to unity. It seems necessary to conclude, therefore, that some of the ions must have had more than one charge in the data under discussion.

The results in Table 4 were divided into two groups and treated in a manner similar to that applied to Table 2. Only nine of the forty sets of observations appear to fall into group (2), but the results of the grouping support in every way the conclusions drawn from the discussion of Table 5. A table showing the grouping of data from Table 4, however, will not be presented here, as it adds no new material for discussion; it should be mentioned, before leaving the matter, that the values of $N_\pm/N_A$ are 0.13 and 0.25 for groups (1) and (2), respectively, instead of 0.10 and 0.20 as in Table 5.

Conclusion

At Washington, D. C., the nuclei-content of the atmosphere appears to increase in winter to two or three times its value in summer, and it appears that the ratio of uncharged to total nuclei, N_0/N_A, increases with increasing nuclei-content. Consideration of the work of other investigators seems to support the latter conclusion.

The results presented, treated as a whole, indicate that the number of large ions, when added to the number of uncharged nuclei in the atmosphere, accounts for all the nuclei; thus, $N_0 + 2N_\pm = N_A$. This conclusion is based on independently observed values of N_0, $N_\pm$, and N_A. Arising out of this conclusion is the indication that each large ion is singly-charged. It is found that the ratio of the number of uncharged nuclei to the number of large ions of one sign, $N_0/N_\pm$, is 5.8. However, the data are susceptible of other treatment, and the results so obtained point to somewhat different conclusions.

The chief result of the new treatment is the indication that the large ions in the free atmosphere, at times, carry more than one charge. There is indication, also, that a few per cent of the nuclei are lost in the apparatus, but there is no information as to how many of the lost nuclei are charged and how many uncharged. Added support is given to the conclusion that the ratio N_0/N_A increases with increasing nuclei-content. The ratio of uncharged nuclei to large ions of one sign, $N_0/N_\pm$,

under the new treatment becomes 7.0. Values of the electronic charge per large ion of 0.85 for certain of the observations and about 1.4 for the remaining, suggest the need of some adjustment of the data to obtain integral values; any method of adjustment which brings 0.85 up to unity will also raise the 1.4 value toward 2.0, and, therefore, the possibility that large ions are at times multiply-charged cannot be readily dismissed.

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ON THE VALUE OF THE RATIO OF THE NUMBER OF UN-CHARGED NUCLEI (N_0) TO THE NUMBER OF CHARGED NUCLEI OF ONE SIGN ($N_\pm$) AT WASHINGTON, D. C.

By O. W. Torreson

Abstract—According to present conceptions of the mechanism of ionic equilibrium in the free atmosphere, the ratio $N_0/N_\pm$ is a constant. This requires that the ratio $N_\pm/N_A$, where N_A is the total number of nuclei per cc in the atmosphere, also be a constant. Attention is directed to published data showing the diurnal variation in charged nuclei of one sign (N_+) in March 1932, and to other data showing the diurnal variation in total nuclei (N_A) in the same month though in different years. From these data a curve for the diurnal variation in the ratio N_+/N_A is obtained, and it is seen that the ratio is not constant through the day but changes considerably and has a maximum value about 5 or 6 hours, 75° west meridian mean time. Whether the variation is real or is due to instrumental or observational difficulties must be found from future investigations. The highest value of the ratio occurs at the time of highest humidity and the suggestion is made that nuclei, laden with moisture, at such times are caught in the passages of the Aitken counter and values of N_A then obtained are too small. If this occurs, it is of concern to the many users of Aitken counters.

There now seems little reason to doubt that ionic equilibrium in the free atmosphere is determined not only by the rate of production of small ions and their rate of disappearance due to recombination among themselves, but also by the rate of combination of the small ions with uncharged condensation-nuclei and with large ions (charged nuclei). The combination of small ions with uncharged nuclei is believed to result in the formation of large ions and their combinations with large ions of opposite sign to result in formation of uncharged nuclei.

In 1925, Nolan, Boylan, and De Sachy[1] presented theoretical grounds for assuming that

$$\eta_2/\eta_1 = N_0/N_\pm = \text{a constant} \tag{1}$$

where η_1 and η_2 are the combination-coefficients between small ions and uncharged nuclei and large ions, respectively, N_0 is the number of uncharged nuclei per cc, and N_- the number of pairs of large ions per cc in the atmosphere. Various determinatons have been made of the ratio $N_0/N_\pm$, and several results have given values lying between 2.0 and 3.0. In most of these cases, however, N_0 and N_- have not both been observed; one or the other has been computed from the equation

$$N_0 + 2N_\pm = N_A \tag{2}$$

when N_0 and N_A in some cases, and N_- and N_A in others, have been observed. In this equation N_A is the total number of nuclei per cc in the atmosphere.

Among results obtained in determinations of N_0 N_- are those of V. Hess at Heligoland in 1928[2], from values of N_- and N_A, giving a mean ratio of 2.2; J. J. and P. J. Nolan at Glencree in 1928-30[3], from values of N_0 and N_A, giving ratios from 2.2 to 4.7 for different wind-directions, as shown by O. W. Torreson and G. R. Wait[4]; H. Israël at Frankfort in 1929[5], from values of $N_\pm$ and N_A, giving a mean ratio of

[1] J. J. Nolan, R. K. Boylan, and G. P. De Sachy, Proc. R. Irish Acad., A, **37**, 1-12 (1925).
[2] V. Hess, Beitr. Geophysik, **22**, 256-314 (1929).
[3] J. J. and P. J. Nolan, Proc. R. Irish Acad., A, **40**, 3-59 (1931).
[4] O. W. Torreson and G. R. Wait, Terr. Mag., **39**, 47-64 (1934).
[5] H. Israël, Beitr. Geophysik, **23**, 144-166 (1929).

10; C. O'Brolchain at Graz in 1931[6], from values of N_0 and N_A giving a ratio of 2.7; G. R. Wait and O. W. Torreson at Washington in 1931[4] from values of N_0 and $N_\pm$, giving a ratio of 5.8; and F. P. Schachl at Innsbruck in 1933[7] based on values of N_0 and N_A (and possibly on values of $N_\pm$ although it is not clearly stated), giving a mean ratio of 2.8. With the possible exception of the work of Schachl, that of Wait and Torreson, from which was obtained the ratio 5.8, is the only work in the group above mentioned in which both N_0 and $N_\pm$ were directly observed. In all the cases cited the observations were confined to portions of the day, in general, to the daylight hours, and there is at present little if any observational material giving values of $N_0/N_\pm$ throughout 24-hour intervals.

From equation (2), if $N_0/N_\pm$ is a constant, then $N_\pm/N_A$ is also a constant, and there are few published data which offer some evidence on the matter of constancy of the latter. Wait in 1931[8], published results of four 24-hour series of measurements of condensation-nuclei (N_A), obtained on the grounds of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington at Washington, D. C., late in March in three different years, 1927-28-30. His results are reproduced in Table 1.

[6]C. O'Brolchain, Beitr. Geophysik, **38**, 4-15 (1933).
[7]F. P. Schachl, Beitr. Geophysik, **38**, 202-219 (1933).
[8]G. R. Wait, Terr. Mag., **36**, 111-131 (1931).

TABLE 1—*Condensation-nuclei* (N_A), *in thousands per cc, as measured with an Aitken nuclei-counter at Washington, D. C.*

$75°$ M. T.	March 21, 1927	March 23-24, 1927*	March 27-28, 1928*	March 27-28, 1930*	Mean of the 4 days
h					
0	7.1	11.5	30.4	13.2	15.6
1	4.7	10.9	28.1	8.8	13.1
2	4.7	14.1	25.7	9.8	13.6
3	5.4	11.4	22.0	13.4	13.0
4	4.9	13.1	18.5	10.8	11.8
5	5.6	11.9	12.2	12.1	10.4
6	5.4	9.3	14.6	14.6	11.0
7	7.5	11.3	14.2	32.1	16.3
8	10.2	23.6	14.6	25.4	18.4
9	17.8	17.1	27.1	37.2	24.8
10	35.4	19.8	38.1	39.7	33.2
11	24.8	27.0	45.0	36.3	33.3
12	24.3	24.3	26.9	37.8	28.4
13	22.8	15.6	33.3	29.2	25.2
14	11.9	15.6	54.7	27.5	27.4
15	14.9	21.1	48.2	31.5	28.9
16	21.8	29.3	42.2	22.0	28.8
17	15.6	18.8	36.9	24.6	24.0
18	35.5	26.0	28.7	36.3	31.6
19	29.5	28.8	46.2	21.6	31.5
20	18.4	22.3	29.2	27.5	24.4
21	28.8	18.1	21.7	21.6	22.6
22	23.1	19.3	26.6	16.6	21.4
23	37.5	13.7	40.4	15.1	26.7
Mean	17.4	18.1	30.2	23.5	22.3

*Each series was begun at 14^h in the earlier date indicated.

The mean curve for the four days is plotted as curve (a) in Figure 1 together with a curve (b) for sixteen complete days of record of positive large ions (N_+) obtained in March, 1932, at a site only a few meters distant from that used for the nuclei-measurements of 1927-28-30. Curve (b) is reproduced from a paper presented by Wait and Torreson in April, 1932, at the thirteenth annual meeting of the American Geophysical Union.[9] If, now, the ratio N_+/N_A, obtained from curves (a) and (b), is plotted, the result is as shown in curve (c) in Figure 1.

It is, of course, well appreciated that the data are not all that could be desired; the observations of N_+ were not obtained simultaneously with those of N_A, and too few days of measurement of N_A are available. However, examination of the four individual series of values of N_A dis-
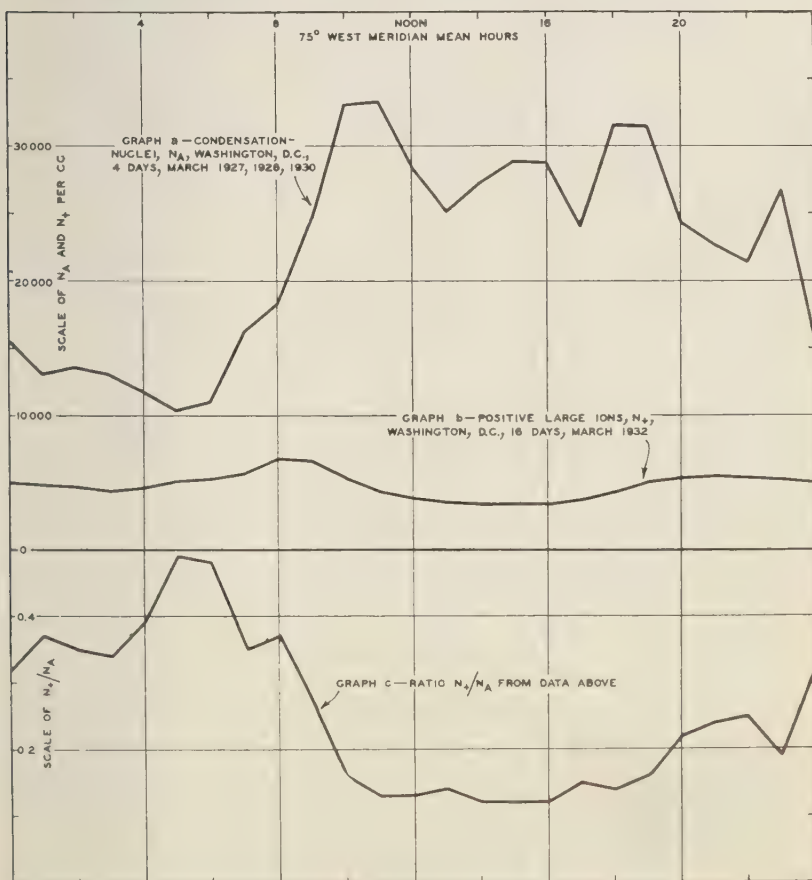
Fig. 1.

closes that all are very similar in character of change through the day, which strengthens belief that they are typical of the diurnal change in total nuclei to be expected in March in any year. Variation through the day in N_+ N_A, taken separately for each of the four days, is therefore similar in character to curve (c) in Figure 1, which shows certain interesting features.

The maximum value of the ratio N_+/N_A occurs at 5^h or 6^h, 75th (west) meridian mean time, after which there is a gradual decrease to about 9^h or 10^h. From 10^h to 18^h or 19^h the ratio is practically constant, after which there is a gradual rise to the maximum at 5^h or 6^h. The maximum value of the ratio at 5^h or 6^h agrees closely with the time of highest humidity. Perhaps part or all of the apparent variation in the ratio may be accounted for if some nuclei become so laden with moisture at times of high humidity as to be readily caught in the passages of the Aitken nuclei-counter, thus causing observed values of N_A at such times to be smaller than the true values. Such a difficulty might be encountered generally by users of Aitken counters.

It is of considerable interest to note, from curve (c), that the mean value of the ratio N_+ N_A for the interval 10^h to 18^h is 0.13. This agrees very well with the value 0.14 found by Wait and Torreson in October and November 1931[4] from an extended series of observations of N_+, N_-, N_0; and N_A, made between 10^h and 18^h on each day of observation. Two widely separated periods of the year are thus shown to have, during daylight hours, the same value of N N_A. The corresponding value of N_0 N_+ during daylight hours in 5.8, as mentioned earlier.

While the evidence cannot be considered conclusive, there is nevertheless an indication that the ratio N_+ N_A (and therefore N_0 N.) undergoes a change through the day, the highest value at 5^h or 6^h being double or more than double that in the daylight hours. If the variation found in N N_A is real, it importantly affects present conceptions of the mechanism of ionic equilibrium; if it is not real it implies instrumental or observational difficulties for which due allowance must be made in interpretation of results. Possible instrumental or observational difficulties might not be confined only to the ion-counter and nuclei-counter used here at Washington but might be encountered with similar instruments used elsewhere. It is of highest importance that additional determinations be made of the ratios N N_A and N_0 N. from observations over 24-hour periods on all four quantities N_+, N_-, N_0, N_A.

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AURORAL OBSERVATIONS AND MAGNETIC CONDITIONS AT THE SITKA MAGNETIC OBSERVATORY, JULY 1932 TO JUNE 1933[1]

By Franklin P. Ulrich

This paper is a continuation of the reports,[2] begun in 1923, of the investigation concerning the relation between aurora and the Earth's magnetic field. The investigation of the Earth's magnetic field and its relation to radio reception was discontinued with the report for 1928-29 because of the lack of proper sensitive instruments and because this investigation is being taken up elsewhere in a more detailed manner than was possible at this Observatory.

Instruments and methods—The instruments and methods as outlined in the report for 1923-24 were used during these observations.

Auroral frequency—The following log shows the frequency of aurora on clear and partly cloudy nights at the Sitka Magnetic Observatory. Observations were made usually up to 23^h and reports after that time were only casual. The number in parentheses indicates the character of the Earth's magnetic field at the time of the observations on the international scale of 0, 1, and 2. All time is standard 135th west meridian time. Due to the absence of the observer from the Observatory, observations were not begun until November 6, 1932.

1932, Nov. 8—Partly cloudy; no aurora; (0). Nov. 9—Clear; no aurora; (0). Nov. 10—Partly cloudy; no aurora; (0). Nov. 11—Partly cloudy 21^h; no aurora; (0). Nov. 12—Partly cloudy; no aurora; (0). Nov. 13—Partly cloudy 21^h; no aurora; (0). Nov. 26—Clear; no aurora; (0). Nov. 28—Clear; no aurora; (1). Nov. 29—Clear; no aurora; (0).

1932, Dec. 5, 6—Clear; no aurora; (0). Dec. 7—Clear; aurora reported between 21^h and $21^h 30^m$; (2). Dec. 8—Clear to 22^h; no aurora; (1). Dec. 9, 10, 11—Clear; no aurora; (0). Dec. 16—Partly cloudy; no aurora; (1). Dec. 17—Clear; no aurora; (1). Dec. 19—Clear; no aurora; (0). Dec. 20—Clear; pale glow along north sky-line; (0). Dec. 21—Clear; no aurora; (0).

1933, Jan 1—Clear after 22^h; no aurora; (0). Jan. 14—Clear; no aurora; (1). Jan. 17—Clear; no aurora; (0). Jan. 18, 21—Clear; no aurora; (1). Jan. 24—Clear; no aurora; (0). Jan. 27, 28—Clear; no aurora; (1).

1933, Feb. 4—Partly, cloudy; no aurora; (0). Feb. 5, 6, 10, 11—Clear; no aurora; (0). Feb. 25, 26, 27, 28—Clear; no aurora; (1).

1933, Mar. 1, 6—Partly cloudy; no aurora; (0). Mar. 7, 8, 10, 11—Clear; no aurora; (0). Mar. 14—Partly cloudy; no aurora; (0). Mar. 18—Partly cloudy at $1^h 45^m$; pale glow and patches of diffused aurora through clouds; (1). Mar. 22—Pale glow along north sky-line at 23^h; (1). Mar. 23—Bright steady glow along north sky-line at 1^h; (1). Clear; no aurora; (1). Mar. 24—Clear; very pale glow along north sky-line; (1). Mar. 25—Clear; pale glow with one small group of rays along north sky-line at $19^h 45^m$; (0).

1933, Apr. 5—Clear at 24^h; no aurora; (1). Apr. 6, 7, 8—Clear; no aurora; (0). Apr. 9—Clear; no aurora; (1). Apr. 11—Clear; no aurora; (0). Apr. 14, 15—Clear; pale glow along north sky-line; (1). Apr. 17—Partly cloudy; no aurora; (1). Apr. 27 —Partly cloudy; no aurora; (0).

1933, May 5, 6—Clear; no aurora; (1). May 7, 9, 10, 16—Clear; no aurora; (0). May 17—Clear; bright aurora at 22^h along north sky-line; (2).

Summary—During this past season there were 68 observations made and aurora was noted 10 times only. There were no auroras on 39, 19, and 0 days when magnetic character-numbers were (0), (1), and (2), respectively, while there were auroras on 2, 6, and 2 days when magnetic character-numbers were (0), (1), and (2), respectively. The two auroras occurring on (0) days were feeble glows, while those occurring on (2) days were bright auroras. On the (1) days the observations showed that "no aurora" was very much more likely than "aurora."

SITKA MAGNETIC OBSERVATORY,
   Sitka, Alaska

LUIGI PALAZZO, 1861-1933

Professor Luigi Palazzo, the eminent director of the Ufficio Centrale di Meteorologia e Geodinamica at Rome, over the destinies of which he presided from 1901 to 1931, and for many years the outstanding geophysicist in Italy, died June 13, 1933, at Florence, in which city he had taken up his residence after his retirement from active duty.

Professor Palazzo was born at Torino, January 18, 1861, and received his early scientific training at the Liceo Cavour and the University of his native city. Even as a student his work here revealed a great love for scientific work and a remarkable precision in the execution of experiments. Upon the completion of his studies at Torino, Palazzo spent two years in perfecting his education at Rome, in the Ufficio Centrale di Meteorologia and in the Physical Institute of the University, devoting his attention chiefly to the theoretical and experimental study of instruments used in terrestrial-magnetic measurements. This sojourn in Rome was followed by two years of study abroad spent in the universities of Würzburg and Berlin, and at the Prussian Meteorological Institute, where he continued to focus his attention on terrestrial magnetism. In November 1887, Professor Ciro Chistoni, who as physical assistant at the Ufficio Centrale di Meteorologia e Geodinamica had already done important magnetic work in Italy, was called to the professorship of physics in the University of Modena, and in August 1888 Palazzo, who had returned to Italy, was appointed his successor as physical assistant at the Ufficio Centrale. As a result of this appointment, the scientific activity of Palazzo was definitely oriented towards geophysics and, more particularly toward terrestrial magnetism. His first assignment was to magnetic field-work in which he distinguished himself by his care in the choice of sites of stations and by the precision of his observations. By 1892 a magnetic survey of Italy proper had been completed and in 1904 the results had been reduced and charts of the three magnetic elements, declination, inclination, and horizontal intensity, could be presented at the Geographical Congress held at Naples that year.

On the retirement of Professor Pietro Tacchini in 1889, Palazzo was made acting director of the Ufficio Centrale, and on August 1, 1901, he was appointed its director. He now turned his attention, with his characteristic zeal, to the execution of the manifold duties connected with that position, and acted as the representative of Italy in all the international activities in which the Ufficio Centrale was concerned. Having brought to conclusion the magnetic survey of the national territory, he now undertook a magnetic survey of the Italian colonies in which work he was engaged intermittently for many years. Meanwhile the examination of the vast observational material secured revealed interesting variations in the magnetic elements at certain stations, and led him to attempt a revision of the magnetic chart of Italy, an enterprise finally completed in 1929.

Thus the magnetic charts representing the condition of terrestrial magnetism in Italy at the close of the Nineteenth Century, together with those representing the work in Eritrea, Benadir, Somaliland, and Oltre-Giuba, the continuous registrations at Terracina, and the new survey for the reconstruction of the magnetic chart of Italy proper begun in 1921 and finished in 1929, constitute enduring monuments to Palazzo's labors. They serve not only for immediate practical purposes but form a part of the vast empirical foundation upon which ultimate theories of the Earth's magnetism must be built.

Palazzo's investigations of geophysics, however, do not pertain alone to terrestrial magnetism; he made also notable contributions to our knowledge of seismology, meteorology, the upper air, and aerial navigation. His aerologcal observations in the Italian colonies in Africa, have thrown much light on the height and temperature of the stratosphere in equatorial regions. His studies of the possible relations between solar radiation and the magnetic elements during eclipses and between the solar and the penetrating-radiation have contributed much toward the solution of important problems in cosmical physics. His numerous publications attest his great activity and the vastness of the fields on which he bestowed his powers of investigation.

In recognition of his important services to science. many honors were bestowed upon Palazzo by the Italian Government and the numerous national scientific bodies of which he was a member. He also took an active part in the international organizations concerned with the work in which he was engaged, particularly in the Section (now Association) of Terrestrial Magnetism and Electricty of the International Union of Geodesy and Geophysics of which he was vice-president from 1922 to 1927.

Palazzo was endowed with a pleasing personality and was much esteemed by all who enjoyed the privilege of his acquaintance. His memory will be cherished not only in his own country where his name symbolizes the recent advancement in magnetic studies but also throughout the scientific world to which he has bequeathed such a wealth of geophysical information.

At the time of his retirement, a considerable sum of money was contributed by his colleagues, friends, and admirers as a memento of their esteem and affection but he arranged that this sum be given to the Reale Accademia dei Lincei for founding a prize, known as the "premio Luigi Palazzo" to be conferred periodically on the author of the best work in geophysics accomplished in an interval of time to be fixed by the Academy.

PROVISIONAL SUNSPOT-NUMBERS FOR DECEMBER, 1933, TO FEBRUARY, 1934

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	Dec.	Jan.	Feb.	Day	Dec.	Jan.	Feb.
1	0	0	11	17	0	11	11
2	0	0	10^a	18	0	..	10
3	0	..	9	19	0	0	8
4	0	0	0	20	0	..	0
5	0	0	$E10^c$	21	0	0	0
6	0	0	11	22	0	..	0
7	0	0	$W19^d$	23	0	..	0
8	0	0	8	24	0	0	$M10^c$
9	0	0	14^d	25	0	0	7
10	0	0	8	26	0	0	0
11	$M9^c$	0	9	27	0	0	0
12	0	$M8^c$	9	28	0	0	0
13	0	11	16	29	0	$E8^c$	
14	0	12	17	30	0	11	
15	..	13	10^a	31	0	..	
16	0	..	11	Means..	0.3	3.1	7.8
				No. days	30	24	28

Mean for the quarter October to December, 1933: 1.5 (83 days)
Mean for the year 1933: 5.4 (343 days)

aPassage of an average-sized group through the central meridian.
bPassage of a larger group through the central meridian.
cNew formation of a large or average-sized center of activity: *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central zone.
dEntrance of a large or average-sized center of activity on the east limb.

Zürich, Switzerland   W. Brunner

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1]

The data for terrestrial magnetism, sunspots, solar constant, and auroræ are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N = k (10g + s)$, where *k* for Mount Wilson is about 0.77.

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 409-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, and 335-339 (1933).

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the Ursigram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in footnotes to the table.

The present values of the solar constant published in these tables are from Table Mountain, California, and have not so great weight as those formerly furnished from Montezuma. The columns headed solar constant show (1) the value in calories of the solar constant, and (2) by letters *s*, *f*, and *u* whether the determination was satisfactory, fair, or unsatisfactory, respectively.

Under the general heading of aurora in the table, the first column gives the character of the day: 0 indicates no aurora; 1, faint; 3, moderate; 5, strong; 7, brilliant; and 9, no observation or no observations possible on account of cloudiness. The second column gives the number of hours during which aurora was present. The third column indicates the amount of sky covered by cloud on a scale of 0-10, where 0 means cloudless, and 10 completely overcast.

Columns four and five describe by letters the form of the aurora,

Summary American URSI daily broadcasts

Date	Magnetism Char.	Type	G.M.T. begin. distur. (h)	G.M.T. begin. distur. (m)	Sun-spot Groups	No.	Solar constant Value	Char.	Aurora Char.	Duration	Cloudiness	Form With-out rays	Form With rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Magnetism Char.	Type	G.M.T. begin. distur. (h)	G.M.T. begin. distur. (m)	Sun-spot Groups	No.	Solar constant Value	Char.
			h	*m*			*cal.*			*hrs*					°		*h*			*h*	*m*			*cal.*	
1	0	...	..	..	0	0	......	...	0	...	5	......	......	..	..		....	...	0	...	..	..	1	2	1.954	*s*
2	0	...	..	..	0ª	0ª	......	...	1	1	3	*HA*	......	0.2	25		*NW-N-NE*	11	0	...	..	..	0	0	1.953	*f*
3	0	...	..	..	0	0	1.942	*s*	1	1	8	......	*R*	0.2	55		*SW-NW-NE*	6	0	...	..	..	0	0	1.955	*f*
4	0	...	..	..	0	0	1.957	*f*	9	...	10	......	......	..	..		....	...	0	...	..	..	0	0	1.954	*u*
5	1	*i*	..	..	0	0	......	...	9	...	10	......	......	..	..		....	...	0	...	..	..	0	0	1.946	*f*
6	1	*i*	..	..	0	0	......	...	1	1	7	*HB*	*R*	0.2	40		*NW-N*	9	1	*i*	..	..	0	0	1.948	*s*
7	1	*i*	..	..	0	0	1.954	*f*	9	...	10	......	......	..	..		....	...	1	*i*	..	..	0	0	1.952	*s*
8	1	*i*	..	..	0	0	......	...	9	...	10	......	......	..	..		....	...	1	*i*	..	..	0	0	1.957	*s*
9	1	*i*	..	..	0	0	......	...	9	...	10	......	......	..	..		....	...	1	*i*	..	..	0	0	1.951	*f*
10	1	*i*	..	..	1	2	......	...	1	1	9	*HB*	......	0.4	45		*W-N-E*	10	1	*i*	..	..	0	0	1.944	*f*
11	1	*i*	..	..	0	0	......	...	1	2	8	*HB*	......	0.2	10		*NW-N-NE*	7	1	*i*	..	..	0	0	1.944	*s*
12	1	*i*	..	..	1	1	1.959	*u*	1	3	7	*HV*	......	0.2	25		*NW-N-E*	11	0	...	..	..	0	0	......	...
13	0	...	..	..	0	0	1.947	*f*	1	1	10	*DS*	*RB*	0.2	90		*NW-N-E*	12	0	...	..	..	0	0	......	...
14	0	...	..	..	0	0	1.945	*s*	9	...	10	......	......	..	..		....	...	0	...	..	..	0	0	......	...
15	0	...	..	..	0	0	1.940	*f*	9	...	10	......	......	..	..		....	...	0	...	..	..	0	0	1.951	*f*
16	0	...	..	..	0	0	1.947	*f*	1	5	3	*HV*	......	0.2	20		*W-N-E*	10	0	...	..	..	0	0	1.949	*s*
17	0	...	..	..	1	1	1.951	*s*	9	...	10	......	......	..	..		....	...	0	...	..	..	0	0	1.952	*s*
18	1	*i*	..	..	0	0	1.951	*u*	5	10	3	*HV*	*RV*	0.8	50		*W-N-SE*	8	0	...	..	..	0	0	1.945	*s*
19	0	...	..	..	0	0	1.951	*f*	0	...	5	......	......	..	..		....	...	0	...	..	..	0	0	1.950	*s*
20	0	...	.. `.`	..	0	0	1.940	*u*	3	8	0	*HV*	*RV*	0.6	45		*W-N-E*	10	0	...	..	..	0ª	0ª	1.957	*s*
21	0	...	..	..	0	0	1.956	*f*	1	4	0	*HV*	......	0.4	30		*W-N-E*	11	1	*b*	1	..	0	0	1.956	*f*
22	0	*p*	8	..	0	0	1.952	*s*	3	8	0	*HA*	*RB*	0.6	50		*W-N-E*	8	1	*p*	..	..	0	0	1.946	*s*
23	0	...	..	..	0	0	1.947	*s*	1	4	1	*HA*	*RB*	0.4	18		*NW-N-NE*	9	0	...	..	..	0	0	1.953	*s*
24	0	...	..	..	0	0	1.952	*s*	3	6	0	*HV*	*RB*	0.4	25		*NW-N-E*	9	0	...	..	..	1ᵇ	2ᵇ	1.955	*f*
25	1	*p*	..	..	0	0	1.955	*f*	1	11	0	*HV*	*RV*	0.2	25		*NW-N-E*	9	0	...	..	..	0	0	1.951	*s*
26	1	...	6	30	1	7	1.957	*s*	1	6	5	*HB*	*R*	0.2	20		*NW-N-NE*	6	0	...	..	..	0	0	......	...
27	0	...	..	..	1	10	1.956	*f*	1	3	7	*HV*	......	0.2	12		*NW-N-NE*	9	0	...	..	..	0	0	1.952	*f*
28	0	...	..	..	2ª	10ª	1.958	*f*	1	6	3	*HV*	......	0.4	20		*NW-N-NE*	10	1	*i*	16	25	..	..	......	...
29	0	...	..	..	2	13	1.963	*s*	9	...	10	......	......	..	..		....	...	0	...	..	..	0	0	......	...
30	0	...	..	..	2	6	1.951	*f*	1	1	9	*HA*	......	0.2	20		*NW-N-NE*	15	0	...	..	..	0	0	......	...
31	0	...	..	..	1	4	1.960	*s*	1	1	5	*HB*	*RB*	0.2	15		*NW-N-NE*	11								
Mean	0.4	.	.	.	0.4	1.7	1.952	.	3.6	4.2	6.1	.	.	.	.		.	10	0.3	..	...	...	0.1	0.1	1.951	...

ªA revision of the value originally broadcast.

column four indicating forms without ray structure and column five, forms with ray structure. The letters employed are the same as those used in the Photographic Atlas of Auroral Forms published by the International Geodetic and Geophysical Union, Oslo, 1930, so far as it was possible to use those letters. For forms without ray structure IIA indicates homogeneous quiet arcs; HB, homogeneous bands; PA, pulsating arcs; DS, diffuse luminous surfaces; PS, pulsating surfaces; G, feeble glow; HV, varied forms; IIF, flaming aurora, and $IIVF$, varied forms with flaming. For forms with ray structure RA indicates arcs; RB, bands; D, draperies; R, rays; C, corona; RV, varied forms; RF, flaming aurora; and RVF, varied forms with flaming.

Column six gives the maximum area of sky covered in tenths of the whole sky, column seven the average altitude in degrees, and column eight the general position of the aurora, being reckoned for included positions in a clockwise direction with Z representing zenith and A the whole sky. The final column gives the Greenwich mean hour of the observed greatest display in the preceding 24 hours of the Greenwich day.

The table of Kennelly-Heaviside Layer heights is self-explanatory.

...smic data, *October to December, 1933*

November Cloudiness	Form Without rays	Form With rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Magnetism Char.	Type	G.M.T. begin. distur. h	m	Sunspot Group	No.	Solar constant Value	Char.	Aurora Char.	Duration	Cloudiness	Form Without rays	Form With rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Date
7	DS	R	0.2	15	N-NE	7	0				0	0	1.954	u	1	2	0	HA		0.2	30	NW-N-E	11	1
7	DS	R	0.2	12	NE	10	0				0	0	1.939	u	1	1	0	HB		0.2	14	NW-N-NE	10	2
7							0				1	1	1.959	f	1	1	0	HV	RV	0.2	40	W-NW-E	11	3
10							1	i			0	0	1.954	f	3	7	0	HV	RV	0.4	35	W-N-E	11	4
10							1	i			0	0			3	7	0	HV	RV	0.4	30	W-NE-SE	8	5
10	DS		0.2	30	N-NE	5	1	i			0	0	1.941	f	1	3	0	HV		0.2	30	NW-N-NE	8	6
10	HB	R	0.2	30	W-NW-NE	8	0	i			0	0	1.976	u	1	1	0	HA	R	0.2	45	NW-N-NE	13	7
7	DS	R	0.4	25	W-N-NE	5	0				0	0			9		10							8
2	DS	R	0.4	25	W-N-NE	5	0				0	0			9		10							9
2	HV	R	0.4	15	NW-N-E	6	1	i			0	0	1.963	u	9		10							10
1	HV	RV	0.6	20	W-N-NE	9	1	i			1	1	1.951	f	9		10							11
10							0								9		10							12
10							0						1.963	f	3	9	0	HV	RV	0.4	60	W-N-E	14	13
10							0						1.959	u	9		10							14
10							0				0	0	1.959	u	1	8	1	HV	RV	0.2	30	NW-N-E	10	15
7	HV	RV	0.2	30	NW-N-E	11	0				0	0	1.936	u	1	5	0	HV	RB	0.2	20	NW-N-NE	12	16
7	G		0.2	20	N-NE	11	0				0	0			1	6	0	HV		0.4	25	W-N-E	12	17
10							0				0ᵃ	0ᵃ			3	10	0	HV		0.4	20	NW-N-E	10	18
5	HV		0.4	35	W-N-E	10	1	i			0	0	1.948	s	3	7	0	HV		0.2	20	NW-N-NE	8	19
1	HV		0.2	20	NW-N-NE	11	0				0	0	1.946	s	1	6	0	HV	RB	0.2	25	NW-N-E	10	20
10							0				0	0	1.954	s	1	5	0	HV		0.2	20	NW-N-NE	10	21
5	HV		0.6	25	W-N-NE	10	0				0	0	1.951	s	9		10							22
3	HV		0.4	30	NW-N-NE	10	0				0	0	1.950	f	0		7							23
9	G		0.2	10	N-NE	10	0				0	0	1.954	s	9		10							24
10							0				0	0	1.961	f	9		10							25
10							0				0	0	1.954	f	1	3	1	HB	RB	0.2	18	NW-NE-E	13	26
10							0				0	0	1.962	u	1	2	0	HA		0.2	15	NW-N-NE	9	27
10							0				0	0	1.950	f	1	6	0	HA		0.2	12	NW-N-NE	13	28
10							1	i			0	0	1.961	u	0		0							29
10							0								1	1	0	HA		0.2	18	NW-N-NE	11	30
							0								1	1	0	HB		0.2	10	NW-N-NE	10	31
0 7.7						9	0.3				0.0	0.0	1.954		3.6	4.0	3.2						11	Mean

i cycle

Kennelly-Heaviside Layer heights, Washington, D. C.

Date	Frequency	Nearest hour G.M.T.	Height	Date	Frequency	Nearest hour G.M.T.	Height
1933	*kc/sec*	*h*	*km*	*1933*	*kc/sec*	*h*	*km*
Oct. 6	2,500	17	No value obtained	Nov. 10	2,750	17	250
" "	2,700	17	150	" "	3,200	17	140, 210
" "	3,040	17	320	" "	3,900	17	290, 440
" "	3,200	17	190	" "	5,000	17	250
" "	4,100	17	340	" "	6,000	17	290, 350
" "	4,400	17	310	" "	7,000	17	320
" "	4,800	17	270	" "	7,200	17	370
" "	5,700	17	370	" "	7,400	17	750
" "	6,000	17	210, 310	" "	9,000	17	900
" "	6,100	17	330	" "	9,200	17	No value obtained
" "	6,400	17	550	" 15	4,400	17	260
" "	6,500	17	No value obtained	" "	4,600	17	250
" 13	2,500	17	130	" "	6,000	17	260
" "	2,920	17	130, 350	" "	7,000	17	280
" "	3,300	17	220	" "	7,400	17	320
" "	4,070	17	360	" "	8,000	17	640
" "	4,400	17	260, 300	" "	9,000	17	810
" "	5,000	17	330	" "	2,500	17	130
" "	5,400	17	340	" "	2,770	17	300
" "	5,500·	17	370	" "	2,950	17	160, 210
" "	5,600	17	330	" "	3,170	17	240
" "	6,000	17	330	" "	3,380	17	220
" "	6,600	17	410	" "	3,880	17	280
" "	6,700	17	No value obtained	" "	4,400	17	250
" 20	2,800	17	110	" 24	2,660	17	120
" "	3,010	17	300	" "	2,720	17	120, 280
" "	3,090	17	200	" "	2,980	17	120, 190
" "	3,200	17	No value obtained	" "	3,800	17	260
" "	3,350	17	210	" "	5,000	17	270
" "	4,060	17	310, 360	" "	5,800	17	280, 340
" "	5,000	17	270, 550, 630	" "	7,000	17	330
" "	5,600	17	140, 300, 480	" "	8,400	17	840
" "	6,500	17	370	" "	8,600	17	No value obtained
" "	6,600	17	850	" 28	2,500	17	150
" "	7,300	17	No value obtained	" "	2,600	17	180
" 27	2,750	17	160	" "	3,000	17	140, 220, 320
" "	2,820	17	260	" "	3,900	17	310
" "	3,170	17	180	" "	4,400	17	290
" "	3,500	17	240	" "	5,400	17	300
" "	6,360	17	230	" "	6,000	17	310, 470
" "	4,050	17	300	" "	6,400	17	300, 690
" "	5,000	17	270, 530, 620	" "	7,000	17	570
" "	7,000	17	280, 370	" "	7,600	17	870
" "	8,300	18	760	" "	8,600	17	880
" "	8,400	18	No value obtained	" "	8,800	17	No value obtained
Nov. 3	2,660	17	140	Dec. 6	2,570	17	150
" "	2,930	17	240	" "	2,650	17	No value obtained
" "	3,100	17	170	" "	2,700	17	240
" "	3,330	17	300	" "	2,800	17	190
" "	3,600	17	250	" "	4,000	17	280
" "	4,000	17	310	" "	4,400	17	270
" "	5,000	17	250	" "	4,600	17	240
" "	6,600	17	290, 430	" "	5,000	17	280
" "	7,900	17	410	" "	6,000	17	300, 370
" "	8,300	17	720	" "	7,000	17	310, 750
" "	8,400	17	No value obtained	" "	7,400	17	810
Nov. 10	2,550	17	150	" "	7,600	17	No value obtained

Kennelly-Heaviside Layer heights, Washington, D. C.—Concluedd

Date	Fre-quency	Nearest hour G.M.T.	Height	Date	Fre-quency	Nearest hour G.M.T.	Height
1933	*kc/sec*	*h*	*km*	*1933*	*kc/sec*	*h*	*km*
Dec. 13	2,000	17	110	Dec. 20	2,770	17	280
" "	2,350	17	120	" "	2,900	17	200
" "	2,400	17	130	" "	3,800	17	270
" "	2,450	17	140	" "	4,600	17	230
" "	2,500	17	110	" "	5,600	17	260
" "	2,650	17	170	" "	5,800	17	300
" "	2,750	17	300	" "	6,000	17	370
" "	2,900	17	170	" "	6,200	17	640
" "	3,030	17	270	" "	6,400	17	720
" "	3,200	17	210	" "	7,000	17	720
" "	4,400	17	260	" "	7,200	17	No value obtained
" "	5,000	17	250	" 27	2,780	17	130, 200
" "	6,000	17	240	" "	2,820	17	180
" "	6,400	17	270	" "	2,870	17	250
" "	6,600	17	320	" "	3,050	17	210
" "	6,800	17	440	" "	3,870	17	290
" "	7,000	17	No value obtained	" "	4,400	17	270
" 20	2,300	17	120	" "	5,000	17	270
" "	2,400	17	130	" "	5,800	17	270, 350
" "	2,500	17	120	" "	6,400	17	300
" "	2,550	17	160	" "	6,800	17	770
" "	2,650	17	190	" "	7,000	17	No value obtained
" "	2,730	17	150				

Philippine Ursigrams were inaugurated on February 19, 1934. Magnetic data in plain language, furnished by the Philippine Weather Bureau, will be broadcast every fifteen days by Naval transmitters at Cavite simultaneously on 56, 8872, and 17744 kc following the regular weather broadcast at 4^h 30^m, Greenwich mean time.

Beginning January 1, 1934, the magnetic information for the URSIgram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, there will be a slight difference in time. Instead of the data covering the 24 hours ending 7 A. M., 105° west meridian mean time, the time covered will be the 24 hours ending at 8 A. M., 75° west meridian mean time, or one hour earlier.

Department of Terrestrial Magnetism,   C. C. Ennis
   Carnegie Institution of Washington,
     Washington, D. C.

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, OCTOBER, NOVEMBER, AND DECEMBER, 1933

In the fourth quarter of 1933 there were no magnetic storms in which the total range in H exceeded 100γ. On October 26 a group of moderate size developed rapidly 4° from the center of the solar disc. No magnetic storm occurred while this group was visible.

Two of the sunspot-groups observed in October were in high latitudes and belonged to the new cycle. Both groups had polarities opposite to those of the waning cycle, indicating that the distribution of magnetic polarities will reverse again at this minimum.[1]

[1]Pub. Astr. Soc. Pacific, **45**, 302 (1933).

Day	October 1933								November 1933								December 1933							
	K_2		HaB		HaD		No. groups	Mag'c char.	K_2		HaB		HaD		No. groups	Mag'c char.	K_2		HaB		HaD		No. groups	Mag'c char.
	A	B	A	B	A	B			A	B	A	B	A	B			A	B	A	B	A	B		
1	0	0	0	0	0	0	0	0	.5	.5	0	0	0	0	1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	0								.5
4	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.5
5	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.5
6	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.5								.5
9	0	0	0	0	0	0	1	.5	0	0	0	0	0	0	0	.5					.5	.5	1	.5
10							0	.5	0	0	0	0	0	0	0	0								
11	0	0	0	0	0	0	1	0	0	0	0	0	.5	.5	0	0								
12	0	0	0	0	.5	0	0	.5	0	0	0	0	.5	.5	0	0								
13	0	0	0	0	.5	0	0	.5	0	0	0	0	.5	.5	0	0								
14	0	0	0	0	.5	0	0	.5	0	0	0	0	0	0	0	0								
15	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	.5	0	1	.5	0	0	.5	.5	.5	0	0	0								
19	0	0	0	0	0	0	0	0	.5	0	.5	0	.5	0	0	0	0	0	0	0	.5	.5	0	.5
20	0	0	0	0	0	0	0	0	1	0	.5	0	0	0	0	0	0	0	0	0	.5	0	0	0
21	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	.5	0	0	0
22	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	.5	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	.5	.5	.5	.5	.5	0	1^a	0	0	0	0	0	0	0	1	0	0	0	0	0	.5	.5	0	0
25	0	.5	.5	1	.5	.5	1	.5	0	0	0	0	0	0	0	0	0	0	0	0	.5	.5	0	0
26	1	1	1	1	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	1	0	1	0	.5	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	1	.5	1	.5	.5	.5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	.5	0	.5	.5	0	0	1	0	0	0	0	0	0	0	0	0								
30	.5	0			0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31																								
Mean	0.2	0.1	0.1	0.1	0.1	0.0	0.4	0.2	0.2	0.2	0.2	0.1	0.2	0.0	0	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1

NOTE.—For explanation of these tables see this JOURNAL, **35**, 47–49 (1930).
^{a} Passage of an average-sized group through the central meridian within 5° of the center of the disc.

PRINCIPAL MAGNETIC STORMS
SITKA MAGNETIC OBSERVATORY
OCTOBER TO DECEMBER, 1933[1]

(Latitude 57° 03'.0 N.; longitude 135° 20'.1 or 9ʰ 01ᵐ.3 W. of Gr.)

Greenwich mean time						Range		
Beginning			Ending			Decl'n	Hor. int.	Ver. int.
1933	h	m	d	h	m	'	γ	γ
Oct. 7	6	30	7	12	30	80	290	281
Nov. 6	13	..	8	16	..	60	132	159

October 7—This storm began with a sudden increase in declination of 40 minutes, followed immediately by a decrease of 58 minutes. This was accompanied by minor changes in the horizontal and vertical intensities, which, however, remained relatively undisturbed until about 9ʰ 30ᵐ. Then the two intensity-components decreased rapidly, all the elements reaching their minimum values at about 11ʰ 10ᵐ. Then they gradually returned to their normal values.

November 6-8—This would be better described as a prolonged period of moderate disturbances than as a storm. The declination seemed to be the most disturbed, although there were occasional rather large fluctuations of the intensity-components. The period generally was characterized by rapid oscillations of relatively small amplitude. The times of beginning and ending of the disturbance are not clearly defined.

<div align="right">JOHN HERSHBERGER, Observer-in-Charge</div>

CHELTENHAM MAGNETIC OBSERVATORY
OCTOBER TO DECEMBER, 1933[1]

(Latitude 38° 44'.0 N.; longitude 76° 50'.5 or 5ʰ 07ᵐ.4 W. of Gr.)

There were no marked disturbances recorded during October to December, 1933.

<div align="right">GEO. HARTNELL, Observer-in-Charge</div>

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

HUANCAYO MAGNETIC OBSERVATORY
OCTOBER TO DECEMBER, 1933

(Latitude 12° 02'.7 S.; longitude 75° 20'.4 or 5ʰ 01ᵐ W. of Gr.)

There were no marked disturbances during October to December, 1933.

<div align="right">J. E. I. CAIRNS, Observer-in-Charge</div>

WATHEROO MAGNETIC OBSERVATORY
OCTOBER TO DECEMBER, 1933

(Latitude 30° 19'.1 S.; longitude 115° 52'.6 or 7ʰ 43ᵐ.5 E. of Gr.)

There were no major magnetic disturbances recorded at the Watheroo Magnetic Observatory during the last quarter of 1933.

<div align="right">W. C. PARKINSON, Observer-in-Charge</div>

REVIEWS AND ABSTRACTS

JENNY, W. P.: *Magnetic-vector study of Kentucky and southern Michigan.* Bull. Amer. Ass. Petrol. Geol., Tulsa, Okla., v. 18, No. 1, 1934 (97-105).

The principle of the magnetic-vector method is briefly explained.

The salient geological features of Kentucky are investigated as to their regional magnetic effects. It is found that the Western and Eastern geoclines show up magnetically as negative anomalies, but that also the Cumberland River arch and the Lexington dome show up as negative anomalies. From this follows that some of the outcropping beds in Kentucky are of a higher magnetic permeability than the underlying beds and Basement complex.

The story of the magnetic-vector map in Michigan reveals a number of magnetic-high trends, which are shown to correspond to known structural trends, such as the Howell-Owosso anticline and the Muskegon anticline. The deepest area of the Michigan basin is indicated by a negative magnetic anomaly.

Practical value and application of the magnetic-vector maps to field-problems is explained by the example of the newly discovered Hart field. Apart from the valuable information obtained by magnetic investigations alone, such investigations are of great help in the interpretation of data gained by other geophysical methods.   AUTHOR

COWLING, T. G.: *The magnetic field of sunspots.* London, Mon. Not. R. Astr. Soc., v. 94, No. 1, 1933 (39-48).

Particularly interesting to the magnetician is the proof which Dr. Cowling presents that Larmor's electromagnetic-hydrodynamic hypothesis of the Earth's permanent magnetic field is untenable. Directing his criticism particularly at Larmor's explanation of the magnetic field observed in sunspots he shows that a magnetic field approximating axial symmetry cannot induce the currents to which it is due and so be self-sustaining. As this is essentially Larmor's theory of the permanent magnetic fields of the Sun and of the Earth, the author concludes that his proof demonstrates it to be fallacious.

As a substitute for Larmor's sunspot-theory Dr. Cowling suggests that the field of the spots may be due primarily to a warping of the general solar magnetic field by motion of the gas in the region of the spots, the concept of circular electric currents about the core of the spots being retained as in Larmor's theory. The new conception is based upon some rather bold speculations which have not as yet been supported by observation, a fact of which the author is expressedly aware.

A. G. McNISH

CENTRAL GEOPHYSICAL OBSERVATORY: *Bulletin of the general magnetic survey 1933.* Part 1. Leningrad, Izdanie Glav. Geofys. Obs., 1933 (55 with 39 maps). 29 cm.

On August 21, 1930, a decision was reached by the National Committee of the U. S. S. R. to execute a general magnetic survey of the Soviet territory, since previous surveys, although representing no little effort, covered only a small percentage of the huge area embraced by the Soviet Union and the inhomogeneity of the data rendered difficult the construction of maps showing the distribution of the magnetic elements. The organization and direction of this new survey was entrusted to the Central Committee of the Hydro-Meteorological Service of the U. S. S. R. and the plan of work called for its completion in 1938. However, the enthusiasm and cooperation of the members

of the Service participating in the work give grounds for the hope that the survey may be finished before the date indicated.

The preliminary results of the undertaking are to be published in a series of "Bulletins of the General Magnetic Survey of the U. S. S. R." of which the first number is now before us. It consists of brief reports by the chiefs of the parties engaged in the work, on the operations during the season 1931 under their charge. These reports deal with the general aspects of the work and the instrumental equipment employed, and are followed by tables containing the names and geographic coordinates of the stations occupied together with the values of declination, inclination, horizontal and vertical intensities, all reduced to the epoch 1931.5. At the end of the Bulletin there are several isomagnetic charts, epoch 1931.5, constructed on the basis of the results obtained and applying to the various regions covered by the individual reports, of which there are 13 in the present Bulletin.

On the completion of the general magnetic survey, it is proposed to publish a complete revision of all the magnetic measurements, reduced to a common epoch, together with cartographic material and descriptions of stations.

The present Bulletin is unfortunately printed on a poor grade of paper and the maps are so greatly reduced that it is at times difficult to make out the names and figures on them.

The execution of the magnetic survey of so large a portion of the Earth's surface will not only be an accomplishment of practical value to the country immediately concerned but should also furnish valuable information on the regions of local disturbance and on secular variation, both of which are of the greatest interest to students of the Earth's magnetism as a whole. H. D. Harradon

Hogg, A. R.: *Atmospheric-electric observations.* Beitr. Geophysik, Leipzig, Bd. 41, Heft 1, 1934 (1-31).

The article is a report on atmospheric-electric observations made between January 1930 and June 1932 at the Commonwealth Solar Observatory, Canberra, Australia. The observations included potential gradient, electrical conductivity, small ions, total number of condensation-nuclei, uncharged nuclei, charged nuclei of mobility less than 0.005 cm/sec/volt/cm and those of mobility greater than 0.005 cm/sec/volt/cm, visibility, barometric pressure, temperature, and relative humidity. In addition, special tests were made of the mobility of the small ions using a Zeleny type of divided electrode and of the number of and mobility of the intermediate ions. From the measured values, certain quantities were computed, namely, air-earth current, ratio of intermediate-ion to large-ion numbers, charge per intermediate ion, rate of ionization in the atmosphere, ratio of positive to negative conductivity, and ratio of positive to negative small-ion numbers. Annual- and diurnal-variation curves are given of various measured quantities and of several computed quantities.

The measured values of the atmospheric-electric elements, together with the computed air-earth current and the computed rate of ionization on the basis of the number of uncharged nuclei, are meaned according to the season and summarized in tabular form as follows:

	Conductivity in 10^{-4} esu		Potential gradient in volts/m	Air-earth current in 10^{-7} esu	Total number nuclei	Small-ion number per cc		Ionization in ions per cc per sec
	Posi-tive	Nega-tive				Posi-tive	Nega-tive	
Summer	1.43	1.49	75	7.3	3295	465	345	12.9
Autumn	1.64	1.63	78	8.4	2110	565	435	13.9
Winter	1.42	1.42	87	8.2	1430	585	470	11.9
Spring	1.47	1.51	84	8.3	2500	680	535	16.2

The conductivity and small-ion diurnal-variation curves show a maximum early in the morning; the potential gradient a maximum at about 0^h G. M. T., or several hours later than over the oceans. The maximum of total nuclei occurred at about 17^h local, or 7^h G. M. T. In drawing the mean diurnal-variation curves, as few as seven values were used for one of the hourly intervals, whereas for the others greater numbers were employed, reaching in one case 419 values. This procedure cannot, of course, be justified, unless it is first shown that the character of the curves are not appreciably altered in so doing.

Tests with a Zeleny divided electrode indicated the presence of intermediate ions of average mobility of about 0.025 cm/sec/volt/cm. The author's argument for a confirmation of the presence of intermediate ions (N_A) as a separate species from the large ions (N_B) based on large values of the ratio N_A/N_B seems to the reviewer to be rather weak on account of the apparent assumption that the large ions have a limiting mobility of 0.0003 cm/sec/volt/cm. In view of the fact that the limiting mobility of the large ions has been found at the Department of Terrestrial Magnetism to be twice as great, the justification for such an assumption may be questioned. Sufficiently large values of the mobility of the large ions would account for the large values of the ratio of N_A/N_B as computed and still allow N_A to be not intermediate ions but large ions. Consequently the presence of large values of this ratio, in the absence of definite knowledge of the mobility of the large ions, cannot be adduced as proof of the existence of intermediate ions.

The article contains much of value, in particular the observations on charged and uncharged condensation-nuclei. The results are all the more valuable coming from that part of the world where so few data have thus far been taken.   G. R. WAIT

Hogg, A. R.: *Some observations of the average life of small ions and atmospheric ionization-equilibria.* Beitr. Geophysik, Leipzig, Bd. 41, Heft 1, 1934 (32-55).

The author states that the main object of this research was to find a n equation to represent equilibrium between rate of ionization and concentration of small ions, large ions, and uncharged nuclei in the lower layers of the atmosphere. The observations were carried out at the Commonwealth Solar Observatory, Canberra, Australia. Determinations were made of the total number of uncharged nuclei, of the number of small ions infree air and inside a closed vessel, of conductivity, of potential gradient, of the number of large ions, of rate of production of small ions inside a closed vessel, and of various meteorological elements. From the observed values, quantities were computed as, for example, the space-charge, air-earth current, average life of the small ions, number of electronic charges per large ion, and the diminution-constant for small ions.

The ionization-observations were made on air drawn from the outside into a zinc vessel having a volume of 51 liters. Four successive potentials were employed, namely, 3, 9, 30, and 70 volts, and the corresponding ionization-currents measured by means of an attached electrometer. The results indicated that the rate of production of small ions inside the vessel was proportional to their production in the free atmosphere. A dimunition in the rate of production was found with increase in wind-velocity, and an increase was accompanied by an increase in the calculated air-earth current.

The average charge per large ion was found to be greater than unity. This was ascribed to the existence of doubly charged large ions. A diminution-constant was deduced from the data; its value varied with total number of nuclei. In the derivation of the equation for this constant, it was ultimately found necessary to assume the presence of three types of uncharged nuclei: (a) Those capable of forming intermediate ions (b) those capable of forming large ions carrying elementary unit-charge and (c) those capable of forming large ions carrying either one or two elementary charges. A recombination-coefficient between charged nuclei of opposite sign was deduced, the

value of which (1.7×10^{-8}) is approximately of an order of magnitude greater than that (1.4×10^{-9}) obtained by Kennedy using another method.

This research work is a valuable contribution to our knowledge of equilibrium-conditions in the free atmosphere as applied to small ions, especially as these conditions pertain to more or less pure country air and to low nuclei-concentrations. The value of the investigation is further enhanced by the fact that simultaneous measurements were made on the several associated phenomena, enabling the author to determine more definitely the relationships between them.   G. R. WAIT

NOTES

1. *Auroral station at College, Alaska*—Professor V. R. Fuller of the Alaska Agricultural College and School of Mines, in charge of the auroral station at College, Alaska, reports that the work on the aurora has progressed rather poorly during the winter of 1933-34. The displays have been of a very weak nature and the extremely severe weather has made photography practically impossible because of frost in the air at low temperatures. The road to station No. 2 has been impassable most of the time; as a result, no photographs were possible at station No. 2 during December 1933 and January 1934. Some parallactic photographs were taken however during February 1934. Professor Fuller is engaged in reducing last year's work; the report on the visual observations is nearing completion and the calculation of the photographs is progressing slowly.

The preparation for the installation of the recording ionosphere-equipment at College under Professor Fuller is practically finished, and the transfer was completed during February 1934. This equipment is that used during the International Polar Year at the College-Fairbanks Station by H. B. Maris and has been loaned for use subsequent to the end of the Polar Year by the United States Naval Research Laboratory. In September 1933, about the time Dr. Maris completed his Polar-Year work at the College-Fairbanks Station, the equipment was moved to the site of the Fairbanks Exploration Company, which Company supplied free current. After Dr. Maris' departure this work was in charge of Professor Fuller, who has the assistance of Corporal Marcus assigned by the Signal Corps of the United States Army. For the installation at College, both the receiver and transmitter will be in the same locality. The performance and records of the equipment are constantly being improved.

2. *Notes on work at Polar-Year stations*—Second International Polar-Year notes—We have received from Dr. D. la Cour, Director of the Danish Meteorological Institute, a brief report on the excellent work done by V. Laursen and his party at the Polar-Year station at Thule, only 2° distant from the Earth's magnetic-axis pole. The party consisted of five men of whom one returned to Denmark after about a month. Arriving at Thule July 8, 1932, the men disembarked on the open shore, erected pavilions for the variometers, and the electromagnetic and magnetic absolute determinations, and established a radio station 700 meters distant which served also for supplying electricity. Besides installing the meteorological apparatus at the main station, a mountain meteorological station equipped with recording instruments was established. These and other necessary arrangements taxed the time of the party. An iceberg was captured and anchored, and pieces were cut and taken ashore to assure during the long winter-night (until July 1933) an abundant supply of clear fresh-water for developing, fixing, and washing of the photographic paper, as well as for household purposes.

Following preliminary trials, the Polar-Year registrations were begun with all three sets of variometers August 1, 1932, at 0^h. The insensitive magnetograph operated throughout the year without any loss of record; the sensitive and quick-run sets suffered a few short interruptions. All the traces are excellent. The same light-bulb served throughout the whole year for the time-marks and curves of the low-sensitivity set, for the time-marks and the 153 beams of light in the quick-run set, and for the curves of the sensitive set. The bulb for the time-marks of the sensitive set had to be replaced twice. The base-line value for H did not change as much as one gamma during the year, and the base-line values for D and Z are also excellent. The temperature-effect was reduced to considerably less than one gamma per degree Centigrade, and the pavilions

served their purpose very well. On the return of the Expedition to Copenhagen, comparisons were made with the absolute instruments at the Rude Skov Observatory and the results in D, H, and Z practically agreed with those obtained before the departure of the party. (For example, the electromagnetic instrument for determining vertical intensity showed a change of only 1.5 gammas.)

In addition to the magnetic work, Mr. Laursen and his party carried out a program of other work. Meteorological records were obtained at the principal station as well as at the mountain station which was visited every fifth day, even during the polar night, and measurements of radiation and polarization as well as cosmic-ray observations were made. The execution of the observations with radiosondes was a fine piece of work, since the instruments received from the U. S. S. R. just before the departure of the Expedition had to be completely overhauled before releasing the balloons. A continual watch was kept at the station for auroræ, and clouds and other phenomena were observed. Several dozen auroral photographs were taken and a large number of fine cloud-photographs were secured which will make possible the publication of a special cloud-atlas of high arctic regions. There is not the slightest doubt regarding the observed heights of the radiosondes and the numerous pilot-balloons, as all were determined by triangulation even during the night.

Dr. la Cour expresses his great satisfaction with the quality of the work at the three Danish Polar-Year stations on the magnetic meridian along the west coast of Greenland, and hopes that the great task of reducing the accumulated data may be accomplished with as much success as has attended their collection.

Directions have been issued by the Director of the United States Coast and Geodetic Survey to E. R. Johnson, observer-in-charge, to close the College-Fairbanks Polar-Year Station on March 31, 1934. It is noted that upon the completion of the Polar Year in September 1933 recording with the insensitive magnetograph and with the earth-current equipment was continued.

3. *Magnetic survey of the United States*—Through engineers employed by the Civil Works Administration in the various states of the United States, reports are being received by the United States Coast and Geodetic Survey on the condition of over 2700 magnetic stations. Pamphlets have been recently issued for magnetic declination in Louisiana and South Carolina.

4. *Note on observatory-publications of the United States Coast and Geodetic Survey*—The Coast and Geodetic Survey has recently received numerous replies to a questionnaire sent out some months ago for the purpose of ascertaining to what extent its five magnetic observatory-publications are actually used and whether complete publication as at present is necessary or whether special reproduction of certain tables as needed would suffice. Incidentally such a questionnaire gives information as to interest in the subject which goes far beyond that particular organization concerned and the results therefore have wide significance.

Replies were received from 25 countries. Seventy per cent of these, including at least one from every country, indicated that the complete publication is used and required; 12 per cent would be satisfied with reproduction of special tables, not, however, the same tables in every case; and 18 per cent have no further need for such publications. Those replying included meteorological and other organizations operating magnetic observatories and making studies in the subject, mapping organizations, libraries, and special investigators both under governmental and non-governmental auspices.

Of the 70 per cent, most of whom reciprocate with similar publications, some emphasized the importance of unbroken series of publications for each magnetic observatory, the length and continuity adding to the value. Some stated that present publication of data should represent a minimum of performance. There proved to be more consultation of copies in libraries than had been anticipated.

5. *Proposed reoccupation of secular-variation stations in Africa*—R. H. Mansfield, now on the staff of the Huancayo Observatory, will take up for the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, beginning in May 1934, reoccupation of magnetic secular-variation stations in Africa from Capetown along the east coast northward to Suez. He will obtain comparisons of his equipment with the absolute instruments used at the Polar-Year observatory at Capetown and with those used by the British East African Meteorological Service at base-station Nairobi (Kenya Colony) and in the magnetic survey of the colonies and territories embraced by the Conference of East African Governors.

6. *Observatorio del Ebro*—Reference has already been made in this JOURNAL (**36**, 256-258, 1931), to the splendid services rendered to the science of geophysics by the Observatorio del Ebro during its quarter-century of uninterrupted activity. This admirable work, which had been declared of "public utility," is now finding itself in a precarious situation and menaced with curtailment or discontinuance because of the withdrawal of the subvention previously accorded by the State. Father Rodés has sent to scientific societies and associations an urgent appeal for pecuniary contributions, however small, towards the support of the Observatory and the publication of its Bulletin. In view of the long and unbroken series of observations, especially in terrestrial magnetism, atmospheric electricity, and earth-currents, the cessation of this work would constitute an irreparable loss to geophysics and it is the fervent hope of this JOURNAL that through generous contributions this calamity may be averted.

7. *New magnetic station near Helsinki*—Following the resolution adopted at the Lisbon meeting of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, recommending the establishment of a magnetic station for quick-run registrations in the vicinity of Helsinki (Helsingfors), the Finnish Academy of Sciences decided on December 9, 1933, to establish such a station as soon as possible. At this station a quick-run registering apparatus supplied by the International Polar Year Commission will be used. The Academy of Sciences has also given its consent to maintain the Observatory at Kajaani until the autumn of 1934, in compliance with the wish expressed by the Association.

8. *Consejo Oceanográfico Ibero-Americano*—The first Ibero-American Oceanographical Conference was originally scheduled to meet at Madrid on June 1, 1933, but for economic and other reasons it was decided to postpone the conference until some time this year. The Executive Committee of the Council announced in December 1933 that the inaugural session of the conference will be held on October 12, 1934.

9. *Errata*—The following corrections are to be made in the December 1933 number of the JOURNAL. On page 338, first column of table, "Jul. 6" should read "Jul. 5"; page 339, the table should be placed at top of page; page 340, at end of fourth line of text the word "to" should be inserted.

10. *Personalia*—Dr. *Harlan T. Stetson*, Director of Perkins Observatory, Ohio Wesleyan University, Delaware, Ohio, has been appointed Research Associate in Geophysics at Harvard University, where he will be in residence until the middle of 1934. During this period personal correspondence should be sent him to the following address: Room 25, Institute of Geographical Exploration, 2 Divinity Avenue, Cambridge, Massachusetts.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—*Terrestrial and Cosmical Magnetism*

Agincourt and Meanook Observatories. Record of magnetic observations at Agincourt and Meanook for 1927. By W. E. W. Jackson, Assistant Director, Meteorological Service of Canada. Ottawa, J. O. Patenaude, 1933 (46 with 11 pages of traces). 29 cm.

Barton, D. C. Magnetic and torsion-balance survey of Munich Tertiary Basin. Bull. Amer. Ass. Petrol. Geol., Tulsa, Okla., v. 18, No. 1, 1934 (69-96 with 11 figs.).

Berroth, A., und A. Scheusener. Erdmagnetische Messungen mit Hilfe der Drehwaage. Zs. Geophysik, Braunschweig, Jahrg. 9, Heft 6/8, 1933 (355-368).

Bombay and Alibag Observatories. Magnetic, meteorological and seismographic observations made at the Government Observatories, Bombay and Alibag, in the year 1931, under the direction of S. K. Banerji. Delhi, Manager of Publications, 1933 (iii+165 with 5 pls.). 34 cm.

Brown, F. C. The magnetic survey of China. Lingnan Sci. J., Canton, v. 12, Sup., May 1933 (101-104).

Burmeister, F. Die Entwicklung der erdmagnetischen Forschung in Bayern. Zs. Geophysik, Braunschweig, Jahrg. 9, Heft 6/8, 1933 (336-341).

Cowling, T. G. The magnetic field of sunspots. London, Mon. Not. R. Astr. Soc., v. 94, No. 1, 1933 (39-48).

De Bilt, Institut Météorologique des Pays-Bas. Caractère magnétique numérique des jours. Tome VII. Avril-juin 1933. Janvier-mars 1933 (errata, suppléments). De Bilt, 1933, 24 pp. 24 cm. [Published under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.]

Egypt, Physical Department. Meteorological report for the years 1927-1930. Cairo, Ministry Pub. Works, Physical Dept., 1933 (v+285). 32 cm. [This is a summary report only for the four years 1927-1930, published in an effort to overcome the arrears due to accumulations of work at the Government Press. The tables giving the daily mean values of the magnetic elements are omitted and the hourly deviations are only given for 8 hours, and the recorded values only, i. e., horizontal intensity, vertical intensity, and declination. The table of mean monthly values including the northerly component, westerly component, and total intensity is retained, as is also the description of the principal magnetic disturbances.]

Jenny, W. P. Magnetische Vektorenmethode zur Erforschung von regionalen und lokalen geologischen Strukturen und ihre Anwendung auf magnetische Störungen über Europa. Beitr. Geophysik, Leipzig, Bd. 40, Heft 2/3, 1933 (187-197). [Summary: The magnetic vector-method endeavors to restrict the multitude of possible geologic interpretations of anomalies by the determination of the intensity and direction in space of the local magnetic forces. Intensity and direction in space are plotted at each station by means of a vector-triangle, the components of which represent the differences between the observed values for the declination, horizontal and vertical intensity, and the respective "normal" values for the same station. From the observed values may be deduced, in accordance with the definition of the "normal" field, the homogeneous terrestrial magnetic field, continental, regional, and local fields. The applicability of the vector-method is shown by a study of the magnetic vector-map of Europe.]
Magnetic vector study of Kentucky and Southern Michigan. Bull. Amer. Ass. Petrol. Geol., Tulsa, Okla., v. 18, No. 1, 1934 (97-105 with 4 figs.).

Leningrad, Observatoire Géophysique Central. Bulletin de magnétisme terrestre et d'électricité atmosphérique No. 17. Leningrad, Izdanie Glav. Geophys. Obs., 1933, 40 pp. 38 cm. [Contains values of magnetic elements at Sloutzk (Pavlovsk) and Sverdlovsk (Ekaterinbourg) for 1929.]

Lovö. Ergebnisse der Beobachtungen des magnetischen Observatoriums zu Lovö (Stockholm) im Jahre 1930. Stockholm, Kungl. Sjökarteverket, 1933 (xvii+80). 32 cm.

Rothé, J. P. Observations magnétiques au Scoresby Sund pendant l'Année Polaire. Paris, C.-R. Acad. sci., v. 197, No. 19, 1933 (1057-1059). [Preliminary discussion of some of the results obtained.]

SAN FERNANDO. Anales del Instituto y Observatorio de Marina, publicados de orden de la Superioridad. Sección 1. Observaciones meteorológicas, magnéticas y sísmicas. Año 1932. San Fernando, 1933 (iii+87). 34 cm.

STEEN, A. S., N. RUSSELTVEDT, AND K. F. WASSERFALL. The scientific results of the Norwegian Arctic Expedition in the *Gjöa* 1903-1906 under the conduct of Roald Amundsen. Part II. Terrestrial Magnetism. Geofys. Pub., Oslo, v. 7, 1933 (309).

THELLIER, E. Aimantation permanente des terres cuites. Paris, C.-R. Acad. sci., T. 197, No. 23, 1933 (1399-1401).

TACUBAYA, OBSERVATORIO ASTRONOMICO NACIONAL. Anuario del Observatorio Astronomico Nacional de Tacubaya para el año de 1934. Formado bajo la dirección del Ing. Joaquin Gallo. Año 54. Tacubaya, Universidad Nacional de Mexico, 1933 (284). 19 cm. [Contains the mean values of the magnetic declination and horizontal and vertical components for the year 1932, and the first six months of 1933, as derived from the magnetograms of the Magnetic Observatory of Teoloyucan, as also the values of the magnetic elements obtained at 15 field-stations by Observer R. O. Sandoval during a magnetic expedition in northern Mexico, May to July 1933.]

B—*Terrestrial and Cosmical Electricity*

ANGENHEISTER, G. Polarlicht. Sonderabdruck aus dem Handwörterbuch der Naturwissenschaften, 2. Aufl., Bd. 8, 1933. Jena, Verlag von Gustav Fischer, 14 pp. 26 cm. [This article embodying the latest information on the aurora is divided into three main sections: 1. Results of observations. 2. Theory of the aurora. 3. Comparison of observation, experiment, and theory.]

AUGER, P., ET L. LEPRINCE-RINGUET. Etude de la variation du rayonnement cosmique entre les latitudes 45° nord et 38° sud. Paris, C.-R. Acad. sci., T. 197, No. 21, 1933 (1242-1244). [Results of observations made on board a vessel on a trip from Le Havre to Buenos Aires and return.]

Variation du rayonnement cosmique suivant la latitude. Nature, London, v. 133, Jan. 27, 1934 (138-139).

BONTCH-BRUEWITCH, M. A. Ionospheric measurements in the polar regions. Nature, London, v. 133, Feb. 3, 1934 (175-176). [Brief account of wireless observations made in connection with the International Polar Year 1932-33 at Murmansk in the U. S. S. R. during June, July, and August 1933.]

BORN, M. Cosmic rays and the new field theory. Nature, London, v. 133, Jan. 13, 1934 (63-64).

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CORLIN, A. Cosmic ultra-radiation and auroræ boreales. Nature, London, v. 133, Jan. 6, 1934 (24-25).
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DANFORTH, W. E., AND M. R. LIPMAN. Experiments on the distribution of low-energy cosmic rays in the atmosphere. Philadelphia, Pa., J. Frank. Inst., v. 217, No. 1, 1934 (73-78).

DAUVILLIER, A. Observation des aurores polaires au Scoresby Sund pendant l'Année Polaire. Paris, C.-R. Acad. sci., T. 197, No. 18, 1933 (997-1000).
Activité cosmique et activité solaire. Observation des rayons cosmiques au Scoresby Sund pendant l'Année Polaire. Paris, C.-R. Acad. sci., T. 197, No. 26, 1933 (1741-1744).

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GOLDSCHMIDT, H. Messungen der elektrischen Leitfähigkeit der Luft in Wahnsdorf. Met. Zs., Braunschweig, Bd. 50, Heft 12, 1933 (494-496).

GOTT, J. P. On the electric charge collected by water drops falling through ionized air in a vertical electric field. London, Proc. R. Soc., A, v. 142, No. 846 (248-268).

HESS, V. F. Die Ionisierungsbilanz der Atmosphäre. Beitr. Geophysik, Leipzig, Supplementband 2, 1933 (95-152). [Ergebnisse der Kosmischen Physik, Band 2.]

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KELLER, W. D. Earth-resistivities at depths less than one hundred feet. Bull. Amer. Ass. Petrol. Geol., Tulsa, Okla., v. 18, No. 1, (39-62 with 17 graphs).

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LOCHER, G. L. Cloud photographs of cosmic-ray Stösse. Philadelphia, Pa., J. Frank. Inst., v. 216, No. 6, 1933 (673-682).

The ionization by cosmic-ray particles and swift beta-particles. Philadelphia, Pa., J. Frank. Inst., v. 217, No. 1, 1934 (39-58).

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NOTICE

[Plate 2]

The (Cheltenham) Magnetic Observatory of the United States Coast and Geodetic Survey, June 1934

(Office and Absolute Observatory at right with Variation-Observatory just showing to rear and Comparison and Test Building at left)

MAGNETIC RESULTS OF THE UNITED STATES EXPLORING EXPEDITION, 1838-1842, LIEUTENANT CHARLES WILKES, COMMANDER

By C. C. ENNIS

A century seems a long lapse of time between the execution of a magnetic survey and the publication of its results. This contribution, containing a considerable number of magnetic results of the United States Exploring Expedition, 1838-42, under the command of Lieutenant Charles Wilkes (1798-1877), United States Navy, is offered not merely from a historical standpoint, but with the hope that it may supply some additional foundational material for investigations of the secular changes in the Earth's magnetism.

HISTORICAL

This Expedition was materialized as the result of an act of the Congress passed May 18, 1836. The act of authorization directed that comprehensive and detailed surveys be made of the multitudinous island-groups of the Southern Pacific Ocean, the Hawaiian Group, and portions of the old "Oregon Territory," besides an investigation of the extreme southern limits of the Antarctic Ocean between the approximate limits of 90° and 160° east longitude. In addition to the hydrographic work entailed by these duties, directions were given for magnetic, meteorological, oceanographic, and graviometric observations, as well as in other branches of science. The Expedition was also instructed to obtain information concerning the social and economic conditions among the natives of the many regions to be visited.

In the words of a commentator writing in 1884, "the United States Exploring Expedition deserves especial notice for one particular—it was the first, and is still the only one fitted out by national munificence for scientific objects, that has ever left the shores of the United States." Although provided for by the Congress in May 1836, the organization of the Expedition was so handicapped by almost insuperable difficulties that it was not until March 1838 that Lieutenant Wilkes was called upon to reorganize it and prevent its apparent collapse. The success of the Expedition is ample proof of the wisdom of his selection as its leader.

The splendidly equipped vessels of the Expedition consisted of the *Vincennes* (flagship), the *Peacock*, the *Porpoise*, the *Relief*, and two tenders, the *Seagull* and the *Flying Fish*.

The squadron sailed from the Virginia Capes August 18, 1838,

headed for Madeira and thence to the Cape Verde Islands. From there it set sail for Rio de Janeiro. During this period the activities of the ships were confined principally to searches for reported shoals and other dangers to navigation. From Rio de Janeiro the course was southward along the coast of South America, with one stop at the mouth of the Rio Negro before arriving at Orange Harbor at the southern limits of the Continent. Rounding Cape Horn the Expedition made its way into the Pacific Ocean, its future home and field of operations, making calls at Valparaiso and Callao for supplies and repairs, before entering upon its various activities.

The results of the Expedition loom most prominently in the countless islands and archipelagoes of the Pacific, the center of operations being the Hawaiian Group, of which complete and detailed surveys were made.

Among other island-groups visited and surveyed, either wholly or partly, are the Low Archipelago or Paumotu Group, Tonga or Friendly Islands, Union Group, Samoan Islands, Phoenix and Ellice Groups, Gilbert Archipelago, Marshall Islands, and Fiji Islands. In addition, attention was given to the several portions of New Zealand.

The survey of the Fiji Islands deserves special mention. The work was carried on under adverse conditions due to the hostility of the fierce cannibal tribes inhabiting the Islands. The whole area surveyed embraces about 95,000 square miles, the Group consisting of 154 islands and 80 reefs. An English writer states: "The Fiji Group is the harvest of the Expedition. D'Urville had been here and partially surveyed it in 1827, but the Expedition made a complete survey of it in all its parts, and for the first time gave the world a correct notion of the extent and products of this noble Archipelago. The details of the customs and ferocity of the inhabitants are given with most intense interest in Volume 3 of the 'Narrative.' One thing, however, ought to be noticed. Lieutenant Wilkes treats the Archipelago as if it had been entirely a new discovery of the American Exploring Expedition." In justice to Wilkes the following statement is quoted from his volume on hydrography, published in 1861, some years before the above criticism was made: "Captain D'Urville, in the *Astrolabe*, visited the Group in 1827 and in 1838, but his stay was short and resulted only in the surveys of a few points, so that the whole field was open to us on our arrival."

Another outstanding achievement of the Expedition was the Antarctic Cruise, as a result of which Wilkes claimed priority of discovery of this land-area and named it the "Antarctic Continent." On this cruise, according to Wilkes, the coast of the Continent was skirted for a distance of 1,500 miles, and the high latitude of 67° was attained in spite of dangerous icebergs and ice-fields. The claim of Wilkes to discovery of the Continent has been, and doubtless will continue to be, a much mooted question, any discussion of which is not considered appropriate here. It is about on a par with the famous Peary-Cook debates.

During the four years' absence from the United States, the Expedition made 234 surveys and determined about 2000 geographical positions, astronomically or trigonometrically. The longitudes obtained depended upon 27 reliable chronometers, and the values have long been noted for their accuracy. In addition, a voluminous amount of data was collected concerning meteorology, surface-temperatures of sea-water, and ocean-

currents. "The world has long known and benefited from the labors of the Exposition in hydrography and geography, in astronomy and meteorology, in botany and horticulture, in philology, geology, and biology," to quote the words of G. W. Littlehales.

According to Senate Report No. 391 of the second session of the Thirty-fifth Congress, the plans for the publication of the results provided for 24 volumes and 14 atlases, and on March 3, 1859, there had been published: Narrative, volumes 1 to 5 with atlas; Philology, volume 6; Zoophytes, volume 7 with atlas; Ornithology and Mammalogy, volume 8 with atlas; Races of Men, volume 9; Geology, volume 10 with atlas; Meteorology, volume 11; Mollusca, volume 12 with atlas; Crustacea, volumes 13 and 14 with two atlases; Botany, volume 15 with atlas; Ferns, volume 16 with atlas; and Herpetology, volume 20 with atlas. Further, there were then in process of printing: Botany, by Torrey, volume 17 with atlas; Botany, by Gray, volume 18 with atlas; and Hydrography, volume 23 with two atlases. The manuscripts then completed or nearly completed were: Geographical Distribution of Plants, by Pickering, volume 19; and Ichthyology, by Agassiz, volumes 21 and 22 with two atlases. The manuscript for Physics, presumably largely by Wilkes, volume 24, was in progress. Volumes 17 with atlas, 19 and 23 with two atlases were finally printed, but volumes 18, 21, 22, and 24 were never completed.

At the outset Wilkes met with a serious difficulty, namely, the obtaining of the necessary instrumental equipment, since satisfactory ones could not be procured in this country. On this subject Wilkes writes: "I was directed to proceed to Europe with positive instructions to return in six months, or by the end of January 1837; this left me about 100 days to effect the object in, consequently I could not expect to have any instruments constructed, and little time to complete any that might be found unfinished. On my arrival I found that all the principal instrument-makers were fully occupied and very unwilling to lay aside any of their engagements, and it was only by representing the great objects of the Expedition, and their becoming interested in them, that they were induced to furnish those I was in search of. . . . This interest was equally participated in by many gentlemen, who although they had been a long time waiting for instruments, came forward and desired that their orders might be laid aside or postponed." Fortunately such a spirit of cooperation among those interested in the advancement of science has continued to the present time. The instrumental equipment procured may be classified under the general heads—astronomical and surveying, meteorological and physical, and magnetic.

Magnetic Observations

Concerning the magnetic results of the Expedition included in this paper, a bit more of history may be of interest if not essential.

Some years ago, G. W. Littlehales, well-known Hydrographic Engineer of the United States Hydrographic Office, learned of the existence of some of the records of the Expedition in the home of the daughters of Wilkes, who were then residents of Washington. Always zealous in such matters, he was instrumental in securing their transfer to the archives of the Hydrographic Office. This material consisted of ship's-journals, chronometer books, and fragmentary portions of manu-

TABLE 1—*Values of horizontal intensity and inclination at land-stations, observed by the United States Exploring Expedition, 1838-1842, Lieutenant Charles Wilkes, Commander*

Station	Date	Latitude	Longitude east	Hor. intensity — Needles (sets)	Hor. intensity — Value (c.g.s.)	Inclination — Needles (sets)	Inclination — Value	Remarks
New York, N. Y.	Apr. 1837	40 43N	286 00	3 (13)	.2031	2 (2)	72 47N	Columbia College
Washington, D. C.	Jun, Jul. 1838	38 53N	282 59	3 (12)	.1973	5 (28)	71 18N	Geographical coordinates assuming station was near Capitol
	Jul, Aug. 1843	38 53N	282 59	3 (6)	.1970	4 (14)	71 17N	
	Oct. 1844	38 53N	282 59	2 (11)	.1922			
Funchal, Madeira	Sep. 1838	32 38N	343 06	2 (6)	.3130	6 (13)	61 07N	U. S. Consulate
Rio de Janeiro, Brazil	Dec., Jan. 1838, '39	22 53S	316 51			3 (46)	12 56S	Enxados Island
	May 1842	22 53S	316 51			2 (4)	12 40S	Do.
Rio Negro, Argentina	Jan. 1839	41 03S	297 15	2 (6)	.2802	6 (9)	44 40S	Main Point
Orange Harbor, Chile	Apr. 1839	55 31S	291 57	2 (6)	.3247	2 (8)	58 42S	
Valparaiso, Chile	May 1839	33 01S	288 19	3 (10)	.3566	6 (36)	37 15S	
San Lorenzo I., Peru	June 1839	12 05S	282 44	2 (6)	.3561	5 (17)	7 19S	
Callao, Peru	July 1839	12 04S	282 49			7 (23)	7 32S	
Disappointment Islands	Aug. 1839	14 15S	218 49	1 (2)	.3593	2 (5)	26 13S	East end
King's Island	Aug. 1839	15 42S	215 22	1 (1)	.3678	2 (2)	28 44S	North side; entrance to lagoon
Raraka Island	Aug. 1839	16 06S	215 03	3 (9)	.3620	2 (2)	28 36S	
Point Venus, Tahiti	Sep. 1839	17 29S	210 31			7 (57)	28 05S	
Matahiva Island	Jan. 1841	17 29S	210 31	2 (4)	.3610	2 (4)	31 05S	North extreme
Bellinghausen Island	Sep. 1839	14 52S	211 18	2 (2)	.3764	2 (3)	26 52S	
Rose Island	Sep. 1839	15 55S	205 30	2 (7)	.4020	1 (2)	28 57S	
Pago Pago, Tutuila I	Oct. 1839	14 31S	191 53	2 (6)	.3817	1 (1)	28 43S	"Observatory Point"
Apia, Upolu I	Oct. 1839	13 18S	189 22			4 (19)	26 15S	"Observatory"
Sapapale, Savaii I	Oct., Nov. 1840	13 48S	188 19			4 (14)	27 28S	
	Sep. 1841	13 48S	188 19			2 (2)	27 14S	
	Feb. 1839	13 34S	188 19			2 (14)	27 32S	
	Oct. 1839		187 42			2 (6)	25 27S	
Sydney, Australia	Dec. 1840	33 52S	151 17	2 (6)	.2723	7 (51)	63 05S	Fort Macquarie
	Mar. 1840	33 52S	151 17	2 (5)	.2735	2 (12)	63 15S	Do.
Auckland Islands	Mar. 1840	50 55S	166 27			1 (2)	73 51S	
Bay of Islands, New Zealand	Apr. 1840	35 17S	174 07			4 (15)	59 20S	
Tongatabu, Tonga Islands	Apr. 1840	21 07S	184 49	2 (6)	.2878	2 (4)	39 24S	Pangaimotu Island
Levuka, Fiji Islands	May, June 1840	17 41S	178 53	3 (13)	.3575	6 (42)	37 00S	
Fulanga I., Fiji Islands	May 1840	19 04S	181 18	2 (10)	.3475	2 (2)	37 06S	
Nukulau I., Fiji Islands	June 1840	18 10S	178 30	2 (7)	.3574			Center

Station	Month	Year	Lat.	Long.	(obs.)	Intensity	(obs.)	Dip	Remarks
Vendua I., Fiji Islands	July	1840	16 50S	178 14	2 (4)	.3685	1 (2)	33 30S	"Observatory"
Gardner's Island	Aug.	1840	4 38S	185 20	2 (2)	.3670	2 (4)	7 38S	Center
Enderbury Island	Aug.	1840	3 08S	188 46	3 (15)	.3052	2 (4)	2 29S	Center
Honolulu, Hawaiian Islands	Nov.	1840	21 19N	202 08	3 (9)	.3052	6 (32)	41 50N	
Aratika Island	Mar.	1841	15 33S	214 21	3 (6)	.3064	4 (18)	26 15S	West end
Sea Gull Island	Nov.	1840	16 40S	215 46			2 (12)	27 20S	
Mauna Loa, Hawaiian Islands	Dec.	1840	19 28N	204 23				39 44N	"Pendulum Peak"; summit
Hilo Bay, Hawaiian Islands	Dec., Feb.	1840–41	19 44N	204 57	2 (13)	.3120	2 (4)	39 42N	Waiakea
Hull's Island	Dec., Mar.	1840–41	4 30S	187 40	3 (19)	.3062	2 (2)	6 37S	West Point
Lahaina, Hawaiian Islands	Jan.	1841	20 50N	203 19			2 (14)	40 49N	
Mt. Kamlha (? Mt. Kamlii)	Mar.	1841	20 04N	204 17	2 (5)	.3074	2 (2)	40 12N	Hawaii Island; name station illegible in mss.
Drummond Island	Mar., Feb.	1841	1 14S	174 53	2 (7)	.3000	2 (12)	3 14S	
Charlotte Island	Apr.	1841	0 24N	173 02			2 (12)	1 24N	
Port Orchard, Washington	Apr.	1841	47 38N	237 10	1 (2)	.1955	3 (5)	71 27N	Carr's Point
Port Discovery, Washington	May	1841	48 03N	237 10	3 (7)	.1890	2 (2)	72 38N	"Observatory"
Nisqually, Washington	May	1841	47 07N	237 22	2 (13)	.1952	2 (2)	71 12N	
Possession Sound, Washington	May, June	1841	47 57N	237 47	1 (4)	.1946	2 (2)	72 00N	
Penn's Cove, Washington	June	1841	48 29N	237 24	1 (2)	.1958	4 (36)	72 43N	
Birch Bay, Washington	June	1841	48 55N	237 14	1 (2)	.1893	2 (2)	73 29N	
Dungeness, Washington	July	1841	48 12N	236 55	3 (7)	.1936	1 (2)	71 17N	
Point Roberts, Washington	July	1841	48 58N	236 56	1 (2)	.1884	1 (2)	70 48N	
Astoria, Oregon	July, Aug.	1841	46 11N	237 10	3 (15)	.2074	4 (18)	69 58N	Fort George
Vancouver, Washington	Aug., Oct.	1841	45 37N	237 21	3 (18)	.2095	2 (4)	69 44N	Garden of the fort
Sausalito, California	Aug., Sep.	1841	37 51N	237 31	3 (6)	.2575	4 (18)	62 32N	
Wake Island	Oct.	1841	19 17N	166 35	2 (4)	.3027	4 (28)	29 36N	
Manila, Philippine Islands	Dec.	1841	14 35N	120 58	2 (4)	.3616	4 (24)	16 14N	
Caldera, Philippine Islands	Jan.	1842	6 55N	122 01	2 (4)	.3662	2 (12)	1 46N	
Jolo, Sulu Archipelago	Jan.	1842	6 01N	120 56	2 (4)	.3489	2 (12)	0 39S	
Mangsee Islands, East India	Feb.	1842	7 30N	117 09	3 (6)	.3708	2 (12)	2 22N	
Singapore, Straits Settlements	Feb.	1842	1 17N	103 51		.3666	2 (12)	11 43S	
North Island, Sunda Strait	Mar.	1842	5 42S	105 50			4 (24)	28 11S	
Cape Town, Africa	Apr.	1842	33 56S	18 29	2 (4)	.2089	1 (2)	53 12S	Magnetic Observatory
Saint Helena	May	1842	15 55S	354 18		.2736	2 (12)		

script articles by Wilkes. Among the data were the fundamental ele-
ments requisite for the reduction of magnetic horizontal-intensity values
for about 60 land-stations, namely, the times of vibrations of the various
needles, chronometer-rates, and temperatures observed. There were
also compilations by Wilkes of the values of the magnetic inclination
(dip) observed at the land-stations and at sea on board the vessels [8]of
the squadron.

Knowing of the existence of these data, the writer obtained per-
mission of officials of the Hydrographic Office to use them in the prepara-
tion of this paper. Sincere appreciation of this courtesy is hereby ten-
dered Rear-Admiral W. R. Gherardi, Hydrographer, and other officials
of the Hydrographic Office.

It had been the intention of Wilkes to include the results of his mag-
netic observations in the volume on physics, but the Congress becoming
dissatisfied with the mounting costs of the publications containing the
results of the Expedition, ordered a suspension of further activities
along this line.

The magnetic instrumental equipment was as follows: One variation-
instrument (Gambey); one variation-instrument (Dolland); one Gauss
diurnal-variation instrument (Troughton and Simms); one diurnal-
variation instrument (Gambey); one diurnal-variation instrument
(Dolland); two dip-needles each 6 inches (Robinson); two dip-needles
each 12 inches (Gambey); two dip-needles each 6 inches (Dolland);
three intensity-needles (Gambey); two intensity-needles (Dolland);
and Kater's compasses with prismatic eye-pieces.

According to Wilkes, observations of intensity with the dip-intensity
apparatus were made frequently at sea, but at times it was found im-
possible to obviate the motion so as to get results worthy of record.
The dip-needles were used with more success at sea and dependable
results of inclination were obtained. During the observations he re-
sorted to the plan of always keeping the vessel's head in the magnetic
meridian as nearly as possible in order to minimize the effects of the
vessel's local attraction. The instruments were distributed among
the vessels of the squadron; "the principal ones belonging to the Ob-
servatory* were retained on the *Vincennes* under my own charge. The
Peacock, *Porpoise*, and *Relief* had each a set of dip-intensity apparatus,
as well as Kater's compasses, and attached to each were Barlow's plates.
The positions chosen for the observations were those which from ex-
amination were proved as free from local attraction, and marks were
left to show the spot at which experiments were made."

The method of horizontal-intensity observation on shore was that
in vogue at that time, namely, the method of oscillations. The resulting
values, being merely relative, were referred to some base-station for
which an arbitrary value was assumed. With the advent, about 1835,
of the present method of deflections and oscillations, it became possible
to determine absolute values of the horizontal intensity at any station.

The method of oscillations used by Wilkes depends upon the relation,
$HT^2 = H_0 T_0^2$, in which H_0 is the known absolute (or assumed) value of the
horizontal intensity at some base-station, T_0 is the time in seconds of a
given number of oscillations of the needle at the same base-station,
and T is the time of an equal number of oscillations at another station.

*Probably the Naval Observatory is meant here—*C. C. E.*

Date	Latitude		Longitude east		Inclination Needles (sets)	Inclination Value	Vessel*
	°	′	°	′		°	
1838							
Nov. **	3	40N	344	10	1 (1)	25.4N	V
Nov. 7	0	20S	342	00	2 (2)	18.9N	V
Nov. 11	2	56S	339	31	2 (2)	15.7N	V
Nov. 12	4	06S	338	02	1 (1)	14.6N	V
Nov. 13	6	16S	335	35	1 (1)	12.6N	V
Nov. 14	9	00S	333	30	1 (1)	8.4N	V
Nov. 15	11	26S	331	30	1 (1)	4.4N	V
Nov. 16	13	56S	329	42	1 (1)	0.1S	V
Nov. 17	15	56S	327	54	1 (1)	3.3S	V
Nov. 18	18	00S	326	15	1 (1)	6.6S	V
Nov. 19	20	18S	324	30	1 (1)	9.1S	V
Nov. 20	21	18S	323	01	1 (1)	12.1S	V
Nov. 21	21	59S	321	20	1 (1)	14.9S	V
1839							
Jan. 17	34	56S	308	24	1 (1)	37.1S	V
Jul. 19	13	06S	273	03	2 (2)	16.1S	V
Jul. 20	13	37S	270	40	2 (2)	18.6S	V
Jul. 26	15	51S	254	04	1 (1)	28.1S	V
Jul. 27	16	56S	251	43	1 (1)	31.8S	V
Jul. 29	17	54S	247	06	2 (2)	33.2S	V
Jul. 31	17	05S	244	55	2 (2)	30.5S	V
Aug. 1	18	07S	242	46	1 (1)	33.8S	V
Aug. 2	18	09S	241	16	2 (2)	32.0S	V
Aug. 3	18	05S	240	20	2 (2)	32.5S	V
Aug. 4	18	10S	238	56	2 (2)	32.3S	V
Aug. 5	18	08S	237	31	4 (4)	33.1S	V, P
Aug. 6	17	59S	235	41	6 (6)	30.6S	V, P
Aug. 7	18	13S	235	13	2 (2)	27.9S	P
Aug. 9	18	10S	231	36	4 (6)	32.5S	V, B
Aug. 10	18	22S	228	47	6 (6)	31.2S	V, B, P
Aug. 12	18	32S	224	52	3 (3)	31.5S	V, B
Aug. 13	18	31S	224	00	2 (2)	31.6S	V, B
Aug. 17	18	05S	222	47	2 (2)	31.2S	V
Aug. 18	16	33S	221	43	2 (2)	24.8S	P
Aug. 18	16	19S	221	54	2 (2)	24.4S	B
Aug. 19	15	25S	221	21	4 (4)	23.8S	B, P
Aug. 21	14	50S	221	01	2 (2)	23.2S	B
Aug. 22	14	14S	219	58	4 (4)	24.6S	V, B
Nov. 16	17	47S	175	52	2 (2)	37.4S	V
Dec. 28	36	49S	150	58	1 (1)	63.3S	P
Dec. 29	38	37S	150	52	1 (1)	65.9S	P
Dec. 30	40	53S	151	06	1 (1)	68.0S	P
Dec. 31	42	48S	151	47	1 (1)	72.9S	V
1840							
Jan. 3	49	06S	153	31	2 (2)	74.2S	B
Jan. 7	54	40S	160	45	1 (1)	79.1S	P
Jan. 9	58	24S	162	30	2 (2)	81.0S	V
Jan. 9	58	30S	163	30	2 (2)	78.0S	B
Jan. 11a	63	52S	164	55	2 (2)	81.3S	V
Jan. 11	64	20S	164	20	2 (2)	82.6S	B
Jan. 12	64	35S	165	40	2 (2)	82.4S	B
Jan. 13	61	16S	161	03	3 (3)	86.1S	P
Jan. 13	65	08S	163	51	2 (2)	83.2S	B
Jan. 14	62	56S	160	49	3 (3)	85.8S	P
Jan. 15	66	08S	158	20	2 (2)	83.8S	B
Jan. 15	65	25S	159	00	1 (1)	85.5S	P
Jan. 17	.66	20S	157	00	2 (2)	84.2S	B

*V = *Vincennes*, P = *Porpoise*, B = *Porpoise*.   **Day of month not given for this result.
a Observed horizontal intensity, 2 (2), 0.0855.

TABLE 2—*Continued*

Date		Latitude		Longitude east		Inclination Needles (sets)	Value	Vessel*
		°	′	°	′		°	
1840								
Jan.	18	66	08S	154	53	2 (4)	84.8S	V
Jan.	22	66	30S	151	40	2 (2)	85.6S	B
Jan.	23[b]	66	47S	148	10	· 2 (2)	87.7S	V
Jan.	23[c]	66	52S	150	28	2 (2)	86.5S	P
Jan.	23	66	50S	151	25	2 (2)	85.7S	B
Feb.	1	66	15S	138	00	2 (2)	85.4S	V
Feb.	1	64	40S	131	00	2 (2)	85.3S	B
Feb.	7	64	30S	131	30	2 (2)	84.1S	V
Feb.	9	64	50S	111	00	2 (2)	83.4S	B
Feb.	11	65	35S	106	. .	2 (2)	82.2S	B
Feb.	12	65	10S	112	. .	2 (2)	82.2S	V
Feb.	13	64	40S	102	. .	2 (2)	81.0S	B
Feb.	14[d]	66	00S	106	14	2 (2)	82.5S	V
Feb.	17	64	00S	97	04	2 (2)	79.6S	V
Aug.	13[e]	12	00S	181	30	2 (2)	28.8S	V
Aug.	15	7	50S	183	41	2 (2)	18.2S	P
Aug.	18[f]	5	55S	185	20	2 (2)	11.3S	V
Aug.	19	3	46S	184	22	2 (2)	7.0S	P
Aug.	25	1	28S	186	18	2 (2)	3.4S	P
Aug.	26	1	28N	186	26	2 (2)	3.2N	P
Sep.	1	6	06N	189	04	2 (2)	14.8N	P
Sep.	4	1	30N	192	15	2 (2)	2.4N	V
Sep.	9	10	18N	195	56	2 (2)	23.5N	P
Sep.	10.	8	20N	198	50	2 (2)	18.7N	V
Sep.	11	12	27N	196	43	2 (2)	27.3N	P
Sep.	12	12	37N	198	58	2 (2)	28.9N	V
Sep.	16	6	27S	194	04	2 (2)	9.1S	B
Sep.	17	5	18S	193	59	2 (2)	6.3S	B
Sep.	18	3	13S	193	51	2 (2)	1.8S	B
Sep.	18	2	47S	193	45	2 (2)	0.9S	B
Sep.	19	1	00S	193	39	2 (2)	2.1S	B
Sep.	20	0	35N	194	03	2 (2)	5.9N	B
Nov.	22	9	13N	205	14	2 (2)	21.8N	B
Nov.	23	7	37N	205	10	2 (2)	18.9N	B
Nov.	25	6	15N	206	30	2 (2)	16.5N	B
Nov.	27	6	11N	209	. .	2 (2)	17.4N	B
Nov.	29	6	09N	211	36	2 (2)	16.8N	B
Dec.	1	4	25N	211	41	2 (2)	13.1N	B
Dec.	2	2	04N	211	02	2 (2)	7.6N	B
Dec.	3[g]	0	22S	210	27	2 (8)	3.0N	B
Dec.	3	1	02S	210	38	2 (2)	1.0N	B
Dec.	4	1	56S	210	43	1 (1)	0.6S	B
Dec.	4	2	30S	211	06	2 (2)	1.2S	B
Dec.	10	5	00N	200	27	1 (1)	15.2N	P
Dec.	15	4	15N	199	10	2 (2)	16.2N	P
Dec.	23	1	31S	199	33	1 (1)	1.4S	P
Dec.	30	2	58S	200	08	1 (1)	2.8S	P
Dec.	31	2	06S	199	54	2 (3)	1.8S	P
1841								
Jan.	5	2	34S	199	36	2 (4)	0.7S	P
Jan.	6	2	59S	197	49	2 (5)	1.5S	P
Jan.	9	2	57S	189	19	2 (2)	3.4S	P
Jan.	14	19	00S	214	36	2 (2)	31.6S	B
Feb.	9	10	00S	205	41	2 (2)	18.5S	B
Feb.	17	7	55S	201	03	2 (2)	12.4S	B
Feb.	20	5	20S	201	14	2 (2)	5.8S	B
Feb.	22	3	50S	200	42	2 (2)	3.0S	B

*V = *Vincennes*, P = *Peacock*, B = *Porpoise*.
[b] Disappointment Bay, observed horizontal intensity, 2 (2), 0.0486. [c] On the ice.
[d] On the ice. observed horizontal intensity, 2(2), 0.0916. [e] Observed horizontal intensity, 3(5), 0.3576.
[f] Observed horizontal intensity, 3 (6), 0.3671. [g] Mean of 3 positions.

TABLE 2—*Concluded*

Date	Latitude		Longitude east		Inclination		Vessel*
					Needles (sets)	Value	
	°	′	°	′		°	
1841							
Feb. 24	2	00S	199	47	2 (2)	0.0	B
Feb. 26	0	04N	198	23	1 (2)	4.9N	B
Feb. 27	1	50N	198	46	1 (1)	7.8N	B
Apr. 14	26	43N	199	36	2 (4)	49.7N	V
Apr. 19	33	12N	207	24	2 (2)	56.8N	V
Dec. 4	16	08N	186	30	2 (2)	33.7N	V
1842							
Apr. 28	22	30S	1	25	1 (1)	31.9S	V
May 4	13	30S	351	10	1 (1)	11.4S	V
May 5	12	01S	348	56	2 (2)	10.5S	V
May 6	10	40S	347	04	2 (2)	5.9S	V
May 8	9	15S	344	25	2 (2)	1.3S	V
May 9	8	58S	342	42	2 (2)	0.6N	V
May 10	8	30S	341	35	2 (2)	2.6N	V
May 11	7	25S	339	15	2 (2)	6.4N	V
May 12	6	05S	336	55	2 (2)	10.4N	V
May 13	4	12S	334	08	2 (2)	15.3N	V
May 14	3	10S	332	52	2 (2)	18.3N	V
May 15	1	48S	331	05	2 (2)	21.5N	V

*V = *Vincennes*, P = *Peacock*, B = *Porpoise*.

Hence one can readily determine the desired value of H at the latter station.

The observed value of the time of oscillations requires the usual corrections for rate of chronometer, for arc of vibration of the needle as determined from the expression $(1 - \sin a \sin a'/16)$, and for temperature which, as is well known, is derived from the expression $\triangle T = q \, T' \, (t - t')$, T' being the observed time of vibration corresponding to the observed temperature, t', and t the standard temperature to which the observations are to be reduced, which for the Wilkes data was taken as 60°F.

Information was lacking concerning the temperature-coefficients, q, for the various intensity-needles used by the Expedition, so a worthy precedent was followed. Sabine[1] in his reductions of Belcher's magnetic observations on the west coast of America in 1837-40, met with the same difficulty, which he surmounted by using the mean value of the known temperature-coefficients of 29 needles in use about that period, this mean value being 0.00026. To simplify the computations somewhat in the reductions of the Wilkes data, the value, $q = 0.00025$, was adopted, so that we have for this work $\triangle T = 0.00025T \, (60° - t')$.

Wilkes made magnetic observations at the Cape of Good Hope Magnetic Observatory on April 15, 1842, which was fortunate, since it made this station available as a base-station to which to refer his values. The absolute value of the horizontal intensity for the time of Wilkes' visit as determined from the publications of the Observatory was 4.53 British or 0.2089 c.g.s. units. Upon this value depend all the values of H as given in Table 1.

As to the relative merits of the various intensity-needles, Wilkes depended almost entirely on the three Gambey needles, which he designated $G1$, $G2$, $G3$. Occasional use was made of the Dolland needles but they were proven very unreliable. The writer's findings confirm this estimate on the part of Wilkes. After leaving Washington, as shown by the observations at Funchal, Madeira, needle $G2$ compared with

[1]Phil. Trans. R. Soc., **131**, p. 11, 1841.

G1 and G3 evidenced considerable loss in magnetism apparently. This condition existed until the observations at Sydney in December 1839. From this point to the end of the cruise G3 was the offending member; hence, neglecting the discordant values, the results from Washington

FIG. 1—OBSERVED VALUES MAGNETIC INCLINATION, ANTARCTIC CRUISE (DEC. 28, 1839 TO FEB 17, 1840), UNITED STATES EXPLORING EXPEDITION, 1838-42, PLOTTED ON REPRODUCTION SECTION SABINE'S INCLINATION-CHART OF THE ANTARCTIC REGIONS [PHIL. TRANS. R. SOC., 158, PL. XXIII (1868)]

to Sydney depend almost entirely on $G1$ and $G3$, and upon $G1$ and $G2$ from Sydney back to Washington.

In comparing Wilkes' values with one another or with those obtained by other observers, several circumstances must be considered. The methods and instruments of that time did not have the refinement and precision that prevail today; the observations may not have been made at the same spot or at the same time of day; and there may have been at the times of observations disturbances due to magnetic storms or to local influences. With this in mind, it may be stated that Wilkes' values show, on the whole, as good accord with others as might be expected, except those for the highly disturbed localities of Funchal and on the coasts of South America.

It might be of interest to note the high value of H observed at Pago Pago, Samoan Islands, amounting to about 40,000 gammas (0.4015 and 0.4025 c.g.s. units by $G1$ and $G2$, respectively). This region seems to have been a focal area of high values of H. Assuming a linear change in H down to the present time, we have an annual decrease of about 50 gammas, not an unreasonable amount.

There is not much to be said concerning the inclination-values at sea, shown in Table 2. The values obtained on the Antarctic Cruise, during January and February 1840, are worthy of some notice. A maximum inclination of 87°.7 was obtained in "Disappointment Bay" on January 23, 1840. The values of the inclination observed on this Cruise, for the purpose of comparison, have been plotted on the reproduction of a section of Sabine's[2] inclination-chart of the antarctic regions (see Fig 1).

Search has been made for data which might give the results of the Expedition's declination-observations at land-stations, but without any success. They may be reposing in the dusty files of some of the Government archives. There is a considerable amount of data concerning observations of the "variation of the compass" made at sea on several vessels of the squadron, and it is hoped that something may develop from these as material for a second paper.

The results of the United States Exploring Expedition constitute a real monument to Commander Wilkes and his able assistants, and the return of Admiral Byrd from Wilkes' "Antarctic Continent" may signalize the unofficial centennial celebration of this great and fruitful organization.

[2]Phil. Trans. R. Soc., **158**, Pl. XXIII (1868).

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REVIEWS AND ABSTRACTS

VENING MEINESZ, F. A. *Ergebnisse der Schwerkraftbeobachtungen auf dem Meere in den Jahren 1923-1932.* Sonderdruck aus Ergebnisse der Kosmischen Physik, Bd. 2 (Beitr. Geophysik, Supplementband 2), 1933 (153-212 mit 7 Figuren und 4 Karten). [Leipzig, Akademische Verlagsgesellschaft.]

Certainly no one is better qualified to write on the subject of gravimetric results at sea than Dr. F. A. Vening Meinesz of the Netherlands Geodetic Commission, for it is only through his untiring efforts in making observations with an ingenious pendulum-apparatus of his own design, that gravimetric values have been obtained at sea with a precision comparable with that realized on land.

The material in this survey of the results of gravity-observations at sea in the years 1923-32 is treated under four headings:

(I) *Introduction*—This occupies 19 pages, and in preparation for an intelligent understanding of the results discussed later, begins with a statement of the two problems for which gravimetric observations are necessary. These are the determination of the form of the Earth and the distribution of mass in the Earth's crust. Each of these subjects is then discussed in detail. Considerable attention is devoted to the principle of isostatic compensation and to the methods by means of which the anomalies are obtained from the observed values of gravity, and their significance.

(II) *Gravity-determinations at sea*—Here are briefly reviewed the earlier attempts to make gravity-observations at sea by methods not involving pendulums. A list is given of all the sea-expeditions with the number of observations made by each, on which gravimetric results of precision have been obtained with the Vening Meinesz pendulum-apparatus. All the observations with this method were made on board submarines with the exception of a few secured on board the *Carnegie* in the Pacific and a few others made by Dr. Meinesz on board steamers.

(III) *Summary of results*—This topic is treated in six sections, dealing separately with the results obtained in (1) the Atlantic, (2) the Pacific, (3) the Indian Ocean, (4) the Mediterranean and Red Sea, (5) the East Indies, and (6) the West Indies. In each of these sections the general character of the anomalies in the region is indicated, together, in several cases, with a graph or profile of the results obtained from detailed observations along lines crossing the narrow strip of strong negative anomalies such as was found to be a particularly outstanding feature in the gravity-field of the East Indies. Another such profile indicates the change in the anomalies across the Philippine Deep. Two others are given for the region of the West Indies.

(IV) *Discussion of the results*—This discussion falls into two sections in the first of which the importance of the results for the problem of determining the Earth's figure, is briefly considered. The second section, comprising about 25 pages, is devoted to an interpretation of the results and takes up separately those in (1) East Indies, (2) West Indies, and (3) other regions. More space is given to the results in the East Indies for the reason that this is probably the most extensive region of tectonic activity on the whole Earth and for this reason more observations have been made there.

One of the main objects of this section is to find an explanation for the fact that in general the positive anomalies occur over large areas while the negative anomalies occur in more narrow strips. This seems explainable by a downward folding of the Earth's crust along a line, accompanied by an overthrust of material. The relation of the strip of negative anomalies to such features as ocean-deeps, islands, and volcanoes, lends strong support to the view.

A bibliography of the more important papers on the subject concludes the article.

S. E. FORBUSH

AURORAE AND EARTH-CURRENTS

By W. J. Rooney

Abstract—A comparison of auroral observations and earth-current records from the College-Fairbanks Station during the International Polar Year 1932-33 shows considerable agreement between the aurorae and disturbances in the earth-current records. Ccefficients of linear correlation from 0.71 to 0.76 were obtained from the records for 80 clear nights. Effects associated with brilliant isolated auroral displays at College are readily detected in the earth-current records at Tucson, Arizona, and in exceptional cases, in records obtained as far south as Huancayo, Peru. Oscillatcry disturbances in the earth-current records and moving types of aurora, respectively, seem to show the highest degree of correlation. These results are at variance with comparisons of magnetic and auroral records which indicate a lack of relationship between the two phenomena.

It is more than fifty years since attention was first called to the coincidence of brilliant auroral displays and magnetic storms. The manner in which the two phenomena are associated and the degree of relationship existing between them, however, are still open to discussion, not to say controversy, and a fairly wide divergence of opinion can be found on these points. Today the close connection between earth-currents and magnetic activity is undisputed. Hence comparisons of earth-current and auroral records may be expected to throw some light on the question.

During the Second International Polar Year of 1932-33, continuous records of earth-currents and systematic observations of aurorae were made a part of the program at the College-Fairbanks Station in Alaska, operated cooperatively by the Coast and Geodetic Survey, the Department of Terrestrial Magnetism of the Carnegie Institution at Washington, and the Alaska Agricultural College and School of Mines. The auroral observations were made under the direction of Professor V. R. Fuller of the College, and the earth-current records obtained by K. L. Sherman of the Department of Terrestrial Magnetism.

RECORD OF EARTH-CURRENT POTENTIALS, COLLEGE FAIRBANKS, ALASKA
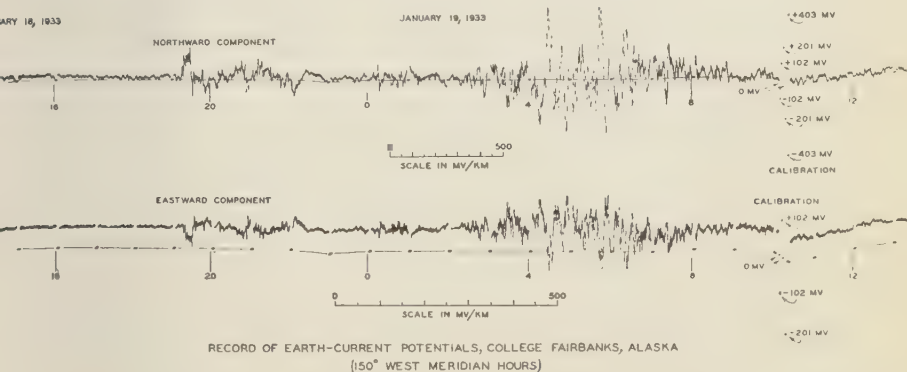(150° WEST MERIDIAN HOURS)

Fig. 1

A typical twenty-four hour earth-current record is shown in Figure 1. This is a moderately disturbed day with character-number 1.4 on a scale from 0 to 2. It will be noted that the trace is fairly calm during the daylight hours but considerably disturbed during the night, and that very little variation in the mean values from hour to hour is ap-

parent. These are distinguishing characteristics of the records from this station. In lower latitudes it is usually found that the short-period disturbances are of about the same order of magnitude as the normal range of the diurnal variation in hourly means. It is only during exceptional storms that they become as much as 20 or 30 times as great. In these polar records, on the other hand, the short-period disturbances are so predominant that the diurnal variation is almost imperceptible when the sensitivity of the recording apparatus is adjusted to secure a complete record of them. The extreme values recorded in a half-hour or less frequently exceed the diurnal oscillatory variation by factors from 50 to 150. These disturbances are often oscillatory like those seen in Figure 1 between 3 and 8 o'clock and, except during periods of severe and protracted magnetic storms, they are practically never found during the hours of daylight.

The auroral work at College included both photographic and visual observations but only the latter have been used in the comparison reported here. At the time of the Polar Year Professor Fuller and his aides were on the fourth year of a five-year program; hence the data contained in their log may be considered as those of experienced observers. Ordinarily the aurora was observed at half-hour intervals during the night with occasional additional observations when auroral conditions warranted them.

Considering the diversity and complexity of the two phenomena and the difference in the two types of record involved it is obvious that an exact comparison is something of a task. Aside from the fact that continuous records of aurora are hardly possible and that variations in atmospheric conditions must influence the observations, the aurorae vary in extent, duration, type, intensity, color, and position, so that a simple quantitative measure can scarcely be applied. The earth-current records are continuous and much simpler, but there are considerable differences in the type and occasionally in the direction of disturbances which should be included in an adequate evaluation.

In spite of the difficulties encountered in establishing a basis for comparison a decided relationship between the two phenomena is indicated by the parallel records. It was found during the progress of the work, for instance, that the general features of the earth-current records with reference to the amount and time of disturbances could be predicted from the auroral log before the grams were developed, and conversely that the auroral conditions could be described in some detail from an inspection of the earth-current record. The agreement is best shown by reference to the records themselves.

During the six months from October 1932 to March 1933 there were 80 nights on which the cloudiness did not exceed 0.3 for more than an hour or two. Condensed records for these 80 nights are shown in the diagrams of Figures 2 and 3. The blocked-in figure for each night gives a simple measure of the amount of disturbance in the earth-current traces for successive half-hourly periods. The height of the block is merely the difference between the largest and smallest deflection during the period, no consideration being given to the type of disturbance, whether a single bay or a number of oscillations. Better measures of disturbance could be chosen but it seemed best, as a first step at least, to avoid any standard which involved judgment as to the relative importance of type. Above the earth-current graphs are found a number of ordinates which represent an equally simple measure of the aurora
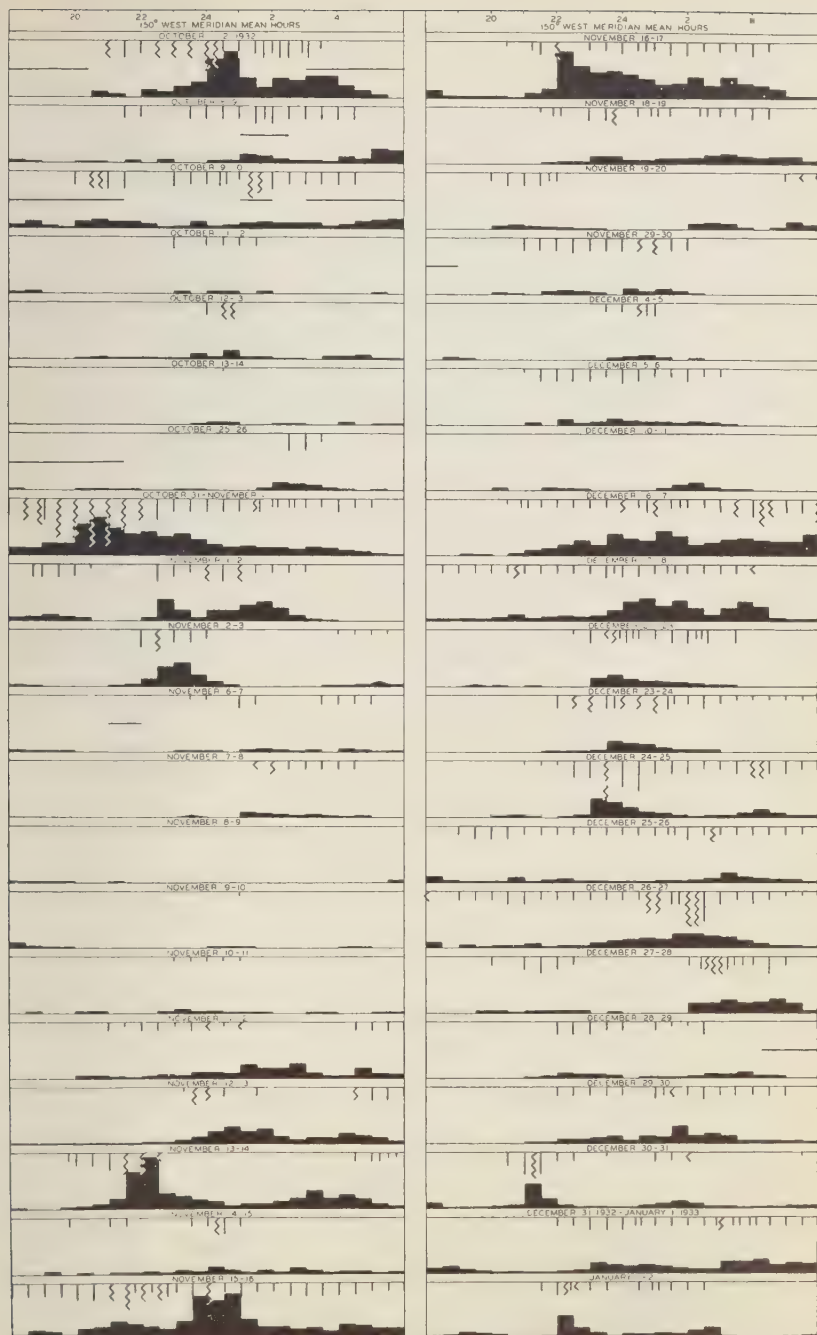
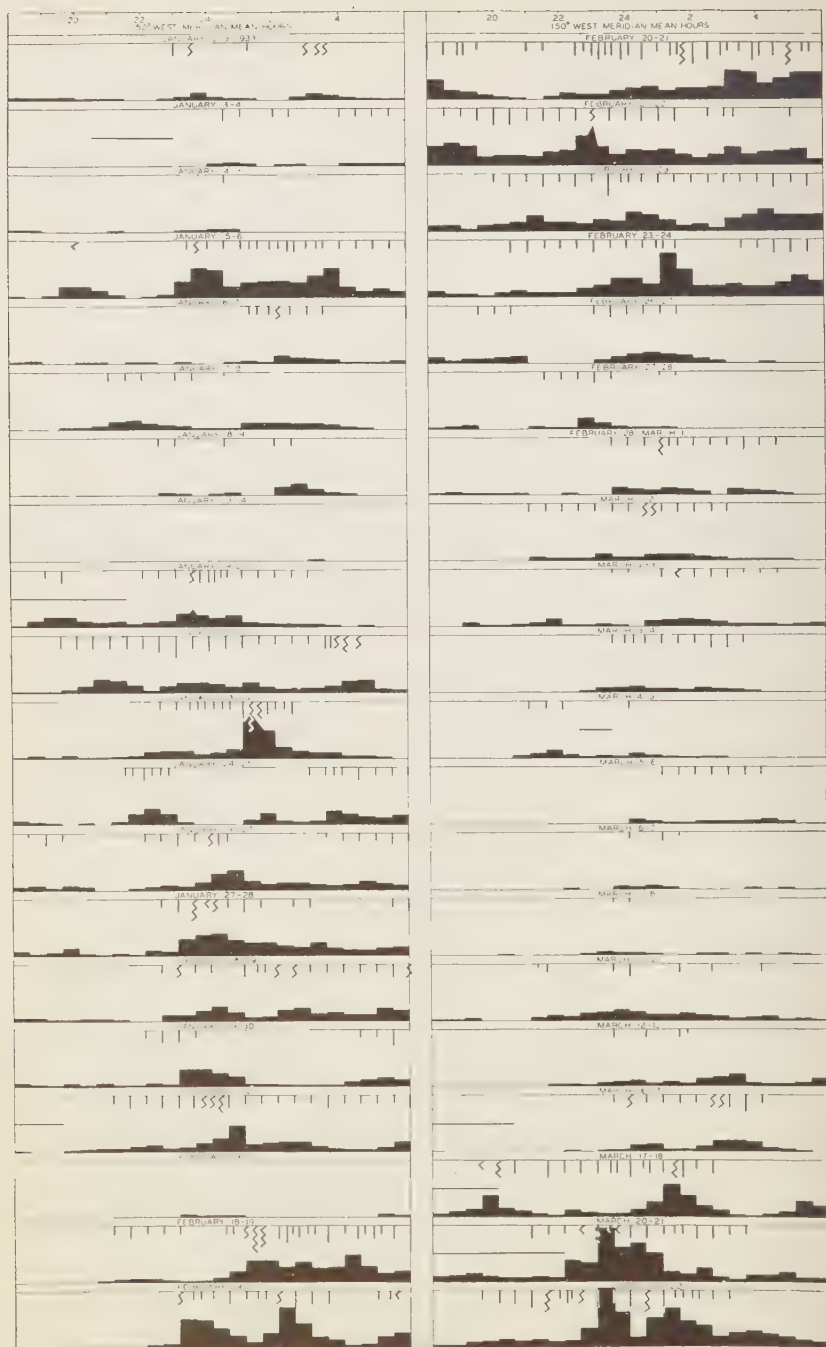EARTH-CURRENT DISTURBANCES AND AURORAE, COLLEGE-FAIRBANKS, ALASKA, OCTOBER 1, 1932 TO JANUARY 2, 1933

LEGEND AND SCALES (ARBITRARY)

EARTH-CURRENT DISTURBANCE: ■ [₀²⁰   CLOUDINESS: ────   AURORA: QUIET ┬[₀°   MOVING ⌇[₀°

FIG. 2

105

EARTH-CURRENT DISTURBANCES AND AURORAE, COLLEGE-FAIRBANKS, ALASKA, JANUARY 2 TO MARCH 22, 1933
LEGEND AND SCALES (ARBITRARY)
EARTH-CURRENT DISTURBANCE   CLOUDINESS: AURORAE QUIET   MOVING

FIG. 3

reported at the various times of observation, usually on the even hour and on the half-hour. The length of the lines is proportional to the sum of the area and intensity of the aurora. Where motion of the aurora was specifically mentioned in the log the lines are jagged instead of straight. Aside from this no attention was paid to the type of aurora in constructing the charts, although in numerous other cases the types reported were those usually associated with motion. The position and duration of the aurorae—except insofar as the latter can be inferred from interpolation between observations—were also neglected for this illustration. Where the notation "very dim" or "scarcely visible" appears in the log, the length of line for aurora specified as area 1 and intensity 1, was made one unit instead of two. About 50 of the 80 nights were cloudless and free from haze. Intervals when the cloudiness was 0.4 or greater are shown by a horizontal line under the auroral ordinates.

Crude as the basis for this comparison is, it seems rather convincing as to the reality of the relationship between earth-currents and aurorae. It is not a one-to-one agreement by any means but an unmistakable correlation is indicated. During large and extended magnetic disturbances we find almost continuous aurorae and, while there are intervals during which there is considerable disturbance in the earth-current traces without any aurorae being reported, there is no single instance where auroral activity in excess of a very minimum display occurs without a noticeable disturbance in the earth-current trace. During intense disturbances there is some quantitative disagreement, the more brilliant auroral displays being reported at times which do not coincide with the maximum disturbance in the earth-current traces. This is almost inevitable in view of the crudeness of the measures used and the intermittent character of the auroral records. The best correlation is found for isolated disturbances and isolated aurorae. The agreement in time and relative magnitude under these conditions is much closer than the charts would indicate.

In order to compare the phenomena quantitatively the factor of linear-correlation was worked out on a number of different bases.

First, the earth-current records for the entire winter were graded according to the customary classification of days from 0 to 2. The days so classified were correlated with an auroral classification based on the number, area, and intensity of aurora reported. The correlation-factor obtained was 0.71.

Second, a similar correlation-factor was determined using the daily means of the ranges during each half-hour as shown in the chart and this independent measure of earth-current disturbance resulted in a correlation-coefficient 0.74.

Third, dividing each night into two halves, the 160 six-hour periods were correlated in the same way with a resulting factor 0.76.

And finally each half-hour period was taken separately on the assumption that the auroral conditions varied uniformly between observations. This procedure puts a severe strain on the auroral data, despite which a coefficient of 0.60 was obtained.

Specific detailed examination of the records indicates that an even higher degree of correlation might be expected if the data were sufficiently numerous to permit segregation in sufficient number of different types of earth-current disturbance and different types of aurora. The moving types of aurora, for instance, appear to affect the earth-current traces

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far more than do homogeneous arcs or glows. Likewise oscillatory-disturbances in the earth-current records are more closely connected with auroral displays—at least with visible auroral displays—than are such slower deflections as bays. "Visible" aurora here does not mean displays not hidden by clouds, but rather displays close enough to be seen at the site at which the earth-current measurements are made. This qualification is stated because reference to the earth-current records at other places shows that none of the disturbances is purely local. In every instance in which a sharp oscillatory-disturbance occurs in the College-Fairbanks record, the earth-current record at Tuscon, Arizona, is disturbed at the same time. The type of disturbance in the

EARTH–CURRENT DISTURBANCES AT COLLEGE-FAIRBANKS, TUCSON, AND HUANCAYO, ACCOMPANYING ISOLATED AURORAL DISPLAY AT COLLEGE-FAIRBANKS, ALASKA, 7 TO 8 GREENWICH MEAN HOURS, DECEMBER 31, 1932

Fig. 4

record at the lower-latitude station is usually less sharp, tending more toward a smooth unidirectional bay. And in the case of a few of the more intense isolated disturbances the effect can be definitely detected, much reduced in magnitude and sharpness, in the records from Huancayo, Peru, in latitude 12° south. Figure 4 shows this better than it can be described. During most of the night of December 30-31, 1932 the aurora observed at College was quite moderate and the earth-current trace of average character (character number 1 or less). Beginning at $7^h 10^m$ Greenwich mean time ($21^h 10^m$ local time) there occurred a very brilliant display of aurora with much motion and color and a diversity of types. The behavior of the earth-currents at the three observatories referred to during this display is shown in Figure 4. Now if such bays as that recorded at Tucson at this time are associated—as they certainly seem to be—with the aurora as seen at College, is it not reasonable to suppose that similar bays in the records of College-Fairbanks, which often occur when no aurora is visible there, are associated with aurora too far off to be observed, say somewhere over on the other side of the zone of auroral occurrence. When the records from the widely distributed stations of the Polar Year have been assembled it may be possible to extend the comparison much further and so to arrive at a more comprehensive picture of the situation.

Brief mention was made in the beginning of the close relationship noted between magnetic disturbances and those in the earth-current records. A similarity in the relationship of the two to auroral activity would consequently be expected. A number of comparisons of magnetic and auroral records have been made, such as those by Wallis (Carnegie Inst. Wash. Year Book 32, 1932-1933, p. 264) using the records of the Byrd Antarctic Expedition in 1929, and by Chree for the British Antarctic expeditions of 1901-04 and 1910-13 and for the Australasian Expedition of 1912-13. The conclusion reached by both was that there is no definite relationship between auroral and magnetic activities. The preliminary report made by Patterson (see Trans. Amer. Geophys. Union, Fifteenth Annual Meeting, 1934) on the comparisons between auroral and magnetic disturbances at Chesterfield Inlet during the Second International Polar Year, however, do indicate considerable correlation, and Sverdrup's (Res. Dep. Terr. Mag., v. 6, 461-511, 1927) observations on the *Maud* Expedition also suggest a connection between the two phenomena. Since it appears that the present comparison shows as a first approximation a fairly high degree of correlation and suggests a connection even closer than that indicated by the coefficients obtained, the evidence from the two sources appears to be somewhat contradictory. It is possible that the connection between earth-currents and aurorae is more direct than that between magnetic activity and aurorae, or it may be that the character of the earth-current variations is such as to bring out the relationship which exists more clearly. In support of the latter explanation is the fact that the higher frequency-components of disturbances are usually emphasized in the earth-current records as compared to those of the magnetic elements. Hence effects associated with aurorae may be less obvious when magnetic records are used in the comparison.

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REVIEWS AND ABSTRACTS

GREEN, A. L.: *The polarization of sky-waves in the Southern Hemisphere.* New York, N. Y., Proc. Inst. Radio Eng., v. 22, No. 3, 1934 (324-343).

In the Southern Hemisphere, and for directions of propagation of downcoming waves very nearly parallel to the lines of force of the Earth's magnetic field, the constants of polarization of sky-waves deviated by the ionosphere at heights ranging between 94 and 262 kilometers have been measured.

At all times the polarization was very nearly circular and right-handed. During the sunrise-period, when measurements were thought to be liable to least error, the average of the ratio of component alternating forces in the downcoming wave was found to be 1.4, the abnormally polarized component being greater than the normally polarized. The angular phase-difference between the components was −84°, the normal component leading the abnormal in time, and the sense of rotation of the resultant magnetic vector in the downcoming wave being clockwise.

At other times, when the experimental conditions were not quite so suitable, due to the presence of multiple reflections and to phase- and amplitude-changes of the sky-waves, the mean constants of polarization were 1°.08 and −89°.6, respectively, again showing circular right-handed polarization.

The experimental conditions were carefully made similar to those of Appleton and Ratcliffe in England, these authors having found circular and left-handed polarization for directions of transmission along the lines of force of the Earth's magnetic field. Their prediction that observations in the Southern Hemisphere for propagation against the lines of force of the Earth's field should show circular polarization with a right-handed sense of rotation, therefore has been verified.

As a consequence of this direct test of the influence of the Earth's field in the production of magneto-ionic phenomena, including the differential absorption in the ionosphere of the right-handed and left-handed components of an incident plane-polarized wave, with the return to the Earth of only one component in each hemisphere, it may now definitely be stated that the origin of abnormal polarization in sky-waves is to be linked up with the Earth's magnetic field.   AUTHOR

WHITEHEAD, T. N.: *The design and use of instruments and accurate mechanism.* New York, The Macmillan Co., 1934 (xii+283). 23 cm.

The book is arranged in two parts. The first is devoted to a discussion of the various errors and the second treats of design. The work is useful alike to the designer, to the instrument-maker, and to the operator or observer. There is much suggested in the matter of mechanical construction especially in Part II on design that is easy of apprehension to any mechanic, although a casual perusal of Part I is likely to discourage the reader not versed in mathematics. Descriptions of instruments, of methods of constructing them, and of the detection of obstacles to precision and of the means of overcoming them, all of which appear frequently throughout the volume, are very interesting to the user of fine instruments.   W. J. PETERS

THE LARGE-ION AND SMALL-ION CONTENT OF THE ATMOSPHERE AT WASHINGTON, D. C.

By G. R. Wait and O. W. Torreson

Abstract—By means of automatic recorders, the small-ion and large-ion content of the atmosphere at Washington, D. C., have been secured. The number of large-ions have been continuously recorded over a period of nineteen months and the small-ions over a period of twelve months. Curves of diurnal variation of large ions and of small ions for the various months of the year are drawn. During the cold season of the year, the large ions pass through maxima in the morning and in the evening. During the warm season, only the evening maximum is present which shows a seasonal variation in time of occurrence. The small-ion variation through the day is more or less reciprocal to the large-ion variation, but is considerably smaller when regarded on a percentage basis. This is largely attributable to the fact that a portion of the current in the small-ion counter is contributed by intermediate ions present in the atmosphere. The large ions and relative humidity vary directly during the cold season and in an inverse manner during the warm season. This change in character from one season to another will be a contributing factor to the daily and yearly changes that occur. The mobility of the large ions, as determined in this investigation, is noticeably greater than that ascribed to them by Langevin, thus indicating that the ions in the two places are not identical in size, unless the difference may be attributed to a difference in experimental conditions.

Simultaneous measurements of the positive large-ion and small-ion content of the atmosphere have been carried on for a period of one year on the grounds of the Department of Terrestrial Magnetism, of the Carnegie Institution of Washington, in northwest Washington, D. C. Air was first drawn through a small-ion counter and the small-ion content was secured, then it was passed through a large-ion counter and the large-ion content was determined. The electric current to the central electrode of the small-ion counter resulted not only from the small ions of the atmosphere, but also from whatever intermediate ions and large ions that may have been present. In drawing the diurnal-variation curves for the small ion no allowances have been made for the contributions by intermediate and large ions, nor in the diurnal-variation curves for the large ion have any allowances been made for the fact that intermediate ions escaping the small-ion counter are caught by the large-ion counter. The terms, "small ions" and "large ions" are understood to refer to the data without any such allowances being made. In the case of the large ions, any such allowances would hardly be appreciable; in the case of the small ions, however, intermediate ions contribute an appreciable part of the total current to the small-ion counter. In a subsequent paper some of the small-ion data corrected for the contributions by intermediate ions will be given and discussed.

A general description of the apparatus used in measuring the small ions and the large ions of the atmosphere in Washington has already been published.[1] Slight modifications and additions were necessarily made in order to secure a continuous record of each class of ions. In the case of the small-ion counter, such modifications consisted for the most part of a relay- and clock-system for automatically turning off and on the air-flow motor once per hour, of another relay for making contact with, and recharging the central electrode-system of the counter, and

[1]Terr. Mag., **39**, 47-64 (1934).

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of the installation of recording appurtenances such as light, clock-movement, and rotating drum for holding the sensitized paper. In order to record the large-ion content of the atmosphere, there was installed a high resistance (about 10^{12} ohms) in parallel with the fiber-system of the electrometer, a relay-system for automatically calibrating the electrometer once per hour, and recording appurtenances similar to that used with the small-ion counter-apparatus. The air-flow was automatically stopped each hour for a period of six minutes, during which time the zero of the large-ion record was secured as well as an insulation-test of the small-ion counter. A small charge was applied to the central electrode of the small-ion counter at the beginning of recording. The sign and magnitude of this charge were such that the central electrode-system passed through a potential corresponding to that of earth at a time about midway between the beginning and end of the hourly interval. The effect of any faulty insulation was in this way made small since during one-half of the hourly interval a charge would leak to the system and during the remaining half it would leak
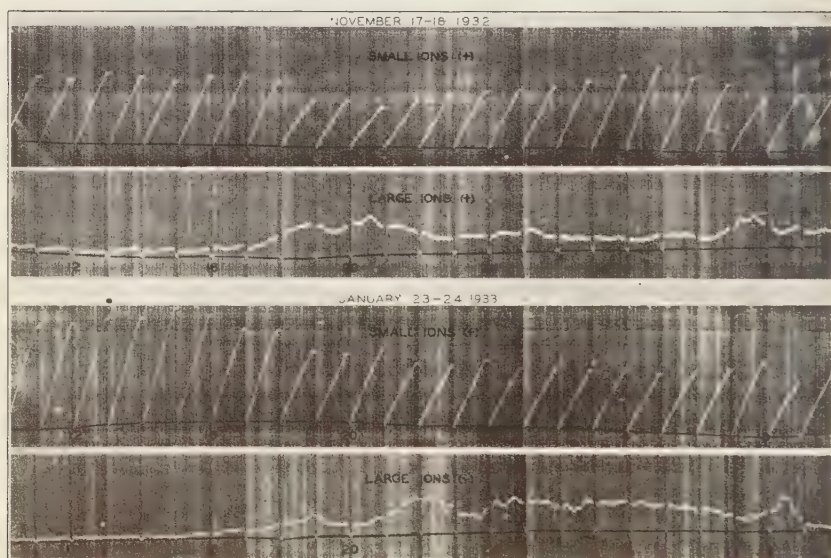

Fig. 1

from the insulated system. Figure 1 shows a typical record of each class of ions, one taken during November 1932 and the other during January 1933. The small-ion apparatus leak-test is easily identified as a short horizontal line at the top of the slanting line. Any effect of faulty insulation is indicated by a downwardly sloping line. The hourly large-ion zero is shown as a dot well below the regular trace. Between succeeding dots an inked line has been drawn to guide the eye along the base-line.

The average number of small ions was secured directly from the slope

of the hourly record, after applying proper scale-value. Likewise, the average number of large ions during any hourly interval was obtained by applying the proper scale-value to the scaled value between the two hourly zeros. Only those days that were complete, or could be so regarded after interpolating over four or less hourly values, were used in deriving hourly means for any month, and any day not complete in both large and small ions was rejected in taking means. All data from
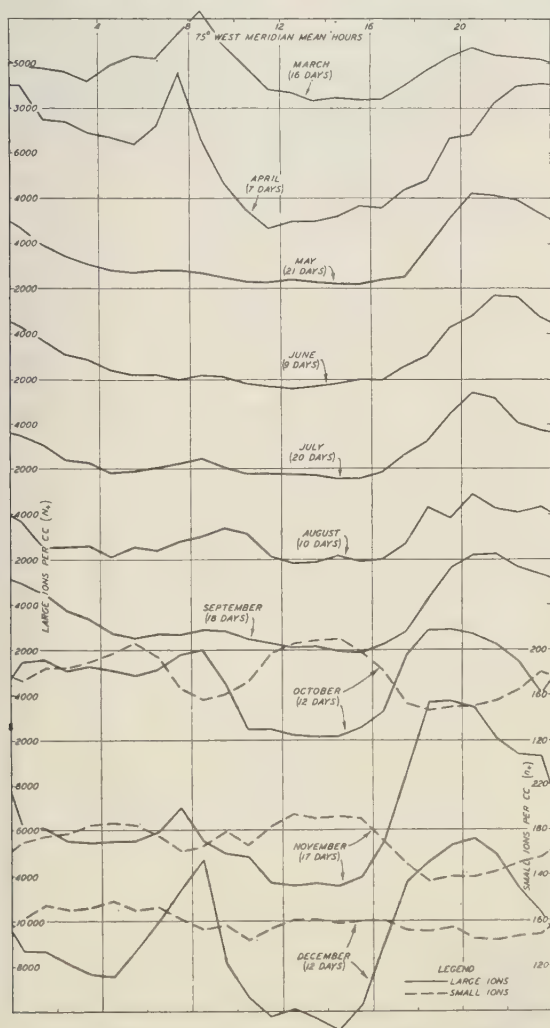

FIG. 28—MONTHLY MEAN DIURNAL COURSE IN POSITIVE LARGE IONS, MARCH TO
DECEMBER, 1932, AND IN POSITIVE SMALL IONS, OCTOBER TO DECEMBER, 1932,
WASHINGTON, D.C.

which curves are drawn are from simultaneous records of large and small ions and always from identical samples of air. This treatment considerably restricted the number of days available for taking means, it was felt, however, that this was justified in view of the greatly enhanced value of the data.

Large-ion data are available for nineteen months, beginning March 1932, while small-ion data are available for eleven months, from October 1932 to September 1933 (except for the month of June). Diurnal-variation curves for the two classes of ions are shown by months, in Figures 2a, b, c, d. During the cold season of the year the number of large ions in the atmosphere undergoes two maxima during the day, one in the morning and the other in the evening. During the warm season,
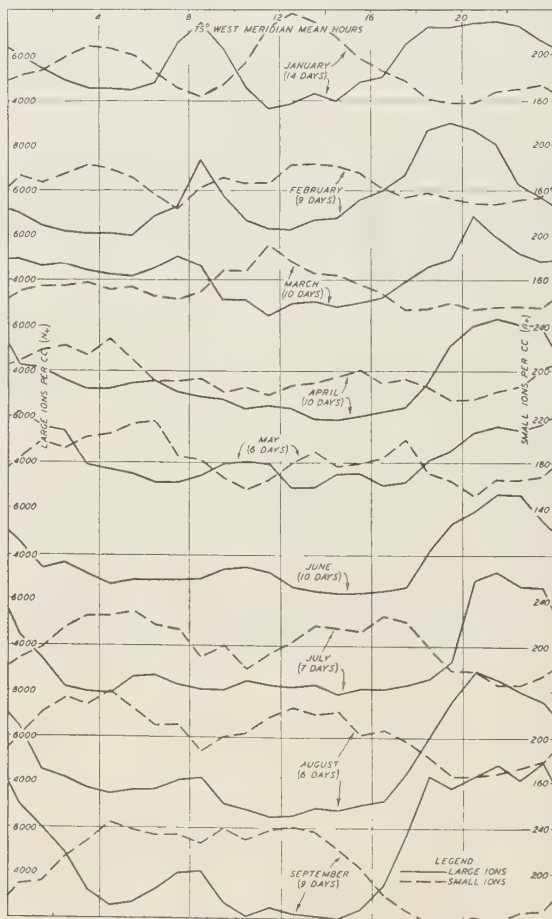

FIG. 2b—MONTHLY MEAN DIURNAL COURSE IN POSITIVE LARGE IONS AND POSITIVE SMALL IONS, JANUARY TO SEPTEMBER, 1933, WASHINGTON, D.C.

only the evening maximum is present; the morning maximum disappears towards the approach of spring and reappears in late summer. One is inclined to associate the appearance of the morning maximum with the beginning of domestic fires upon the approach of cool weather. Although this may be its cause, yet there are inconsistencies in connection with such a theory. The morning maximum begins to appear intermittently as early as August, but cannot be correlated with the appearance of cool weather. It seems likely that the mid-day minimum and the evening maximum may be produced, in part at least, by convection-currents. The rising air-current during the warm part of the day tends to carry the ions upward only to return them with the cooling of the air towards evening. A complicating factor in the diurnal-variation phenomenon of large ions is the apparent change in their character from one season to another. The appearance and disappearance of the
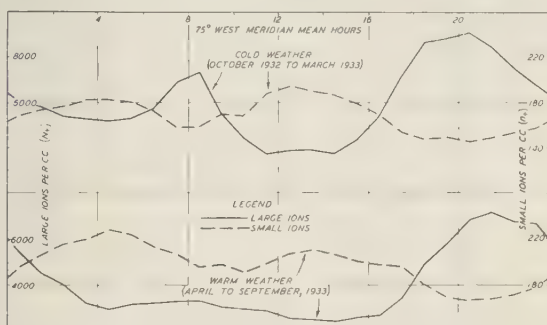

FIG 2c —SEASONAL DIURNAL-COURSE IN POSITIVE LARGE IONS AND POSITIVE SMALL IONS — COLD WEATHER (OCTOBER, 1932, TO MARCH, 1933) AND WARM WEATHER (APRIL TO SEPTEMBER, 1933) WASHINGTON, D.C.
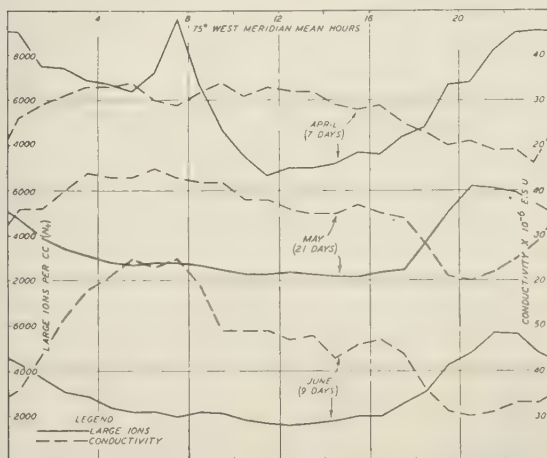

FIG 2d —COMPARISON OF DIURNAL COURSE POSITIVE LARGE IONS AND POSITIVE ATMOSPHERIC CONDUCTIVITY, APRIL TO JUNE, 1932, WASHINGTON, D.C.

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morning maximum may in part be due to a change in the character of the ions. A change in character is indicated by the fact that during the months of May, June, and July the number of large ions varies inversely as the relative humidity, while during the months of December, January, and February the number varies directly as the relative humidity. This change in character no doubt is also a factor affecting the annual variation in the number of large ions (Fig. 3). The number of large
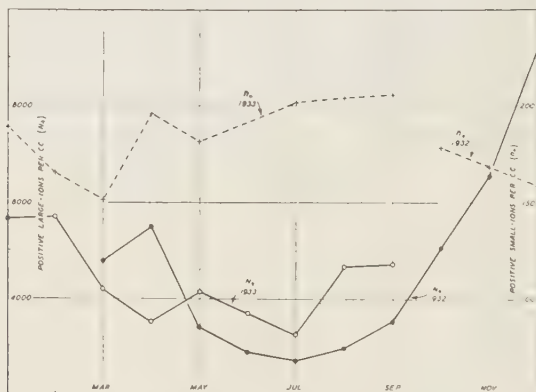

FIG 3—ANNUAL CHANGE IN NUMBER OF POSITIVE LARGE- AND SMALL-IONS
AT WASHINGTON, D C, OCTOBER 1932 TO SEPTEMBER 1933 (122 DAYS)

ions is not greatest during the coldest months when one would expect the greatest amount of smoke distributed into the air by domestic fires. It seems difficult therefore, to ascribe the increase in the number of large ions towards winter entirely to smoke from domestic fires. Additional data secured at a location further removed from the influences of a city might be of assistance in explaining the causes for the observed annual and diurnal variations of large ions.

The positive conductivity of the air was recorded on the grounds of the Department of Terrestrial Magnetism, during the first half of 1932, by K. L. Sherman preparatory to the 1932-33 Polar-Year program at College-Fairbanks, Alaska. The conductivity-apparatus was only a few yards distant from the large-ion apparatus; it is of interest to compare the simultaneously recorded data for conductivity and for large ions. To facilitate such comparison, graphs of the diurnal courses of the elements during April, May, and June, 1932, are shown in Figure 2d. It is evident that, as one would be led to expect from theory, there exists a marked tendency towards a reciprocal relationship between the two elements. It is also of interest to compare the diurnal-variation course of conductivity (Fig. 2d) with that of the small ions for corresponding months of the following year (Fig. 2b). If the operating potential on the small-ion counter too greatly exceeds the critical potential for the small ions, then when high-mobility intermediate ions are numerous, the graph of data obtained by the small-ion counter will be considerably distorted and will only slightly resemble the corresponding conductivity-curve. The operating potential of the small-

ion counter during April and May, 1933, was 29 volts, which corresponded to a saturating voltage for all ions having a mobility greater than about 1.0 cm/sec/volt cm. Under such circumstances, one would expect that the collection of intermediate ions by the small-ion counter was reduced by about the greatest possible amount and consequently that the daily courses of small ions and of conductivity would show considerable agreement. The graphs of Figure 2b do show considerable similarity—as much no doubt as one would expect under the circumstances.

The diurnal variations of small ions and of large ions at Washington, D. C., are quite pronounced, each day's record reproducing the main features, which are well illustrated in the two sets of daily records shown in Figure 1. From these records it will be seen that the small ions vary in a more or less reciprocal manner to the large ions, as required by theory. The small-ion variations on a per-cent basis however, are much less than those of the large ions. The reason is evident when the small ions (n) are plotted to the reciprocal $(1/N)$ of the large ions as has been done in Figure 4, for, although a straight-line relationship is indicated
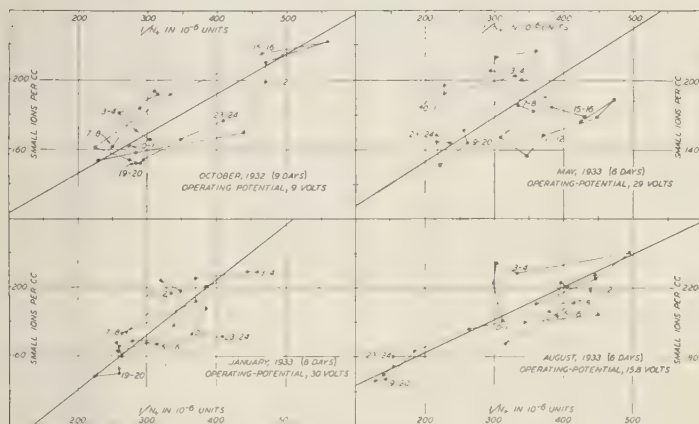

FIG 4—NUMBER OF SMALL IONS AND RECIPROCAL OF LARGE IONS

between n and $(1/N)$, the straight line does not pass through the origin. It was found that the value of n does not become equal to zero when the value of $(1/N)$ becomes zero, due largely to the collection of intermediate ions by the small-ion counter, and not because of any defects in the linear recombination-law between small and large ions. This lack of reciprocal relationship between the small and large ions has been previously observed, and has led to a suggested modification of the linear recombination-law.[2] In a later paper this matter will be gone into and discussed from the point of view indicated above, since we now have available data bearing upon this question.

The mobility of the large ions was found in earlier observations[1] by counting the condensation-nuclei in the air before it passed through the large-ion counter and again after it passed through the counter with

[1] Proc. R. Irish Acad., A, 38, 49-59 (1929).

different potentials applied to the tubes of the counter. The results gave a value for the mobility of these ions, about double that found by Langevin,[3] namely, a mobility of about 0.0003 cm/sec/volt/cm. The mobility of the large ions was measured later on several occasions by varying the potential on the tubes of the large-ion counter and noting the resulting current through the counter. The potentials were altered in a sequence such that the effect of any gradual change in the number of ions in the atmosphere was automatically eliminated. A selected potential was taken as standard, and all potentials applied so that the mean time of operating with a given potential was the same as that of operating with the standard potential. The ratio of the current in the ion-counter during the operation with any potential, to that during the operation with the standard potential was obtained and plotted to the applied potentials. This method was followed in obtaining the plots of ratio of current and applied potentials, as shown in Figure 5. From
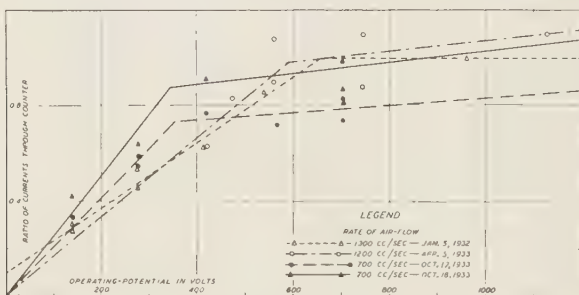

FIG. 5—VARIATION OF CURRENT THROUGH LARGE-ION COUNTER WITH DIFFERENT OPERATING-POTENTIALS

a series of experiments, it turned out that the critical potential (V), at which saturation for a given class of ions occurs, is increased when turbulence takes place inside the air-flow tube. The effect of turbulence may be very pronounced, increasing the critical potential by as much as several fold for turbulent conditions that may sometimes occur in practice. In view of this fact, it is essential that the turbulence-effect be either eliminated or that allowances be made for it in mobility-measurements following this or similar methods.

Tests were made for a turbulence-effect by altering the rate of air-flow and calculating the mobility (K) from the observed air-flow (W), the critical potential in volts (V), and the electrical capacity (C) of the portion of the ion-counter collecting ions, from the equation $K = W/4\pi CV$. If turbulence is effective in altering the value of the critical potential, then with the mobility constant, a lower calculated value of K will result the greater the turbulence-effect, or in other words the greater the rate of air-flow. The results of tests using different rates of air-flow are shown in Table 1, which also contains the observed critical potential and the computed mobility. The constancy of the computed mobility indicates that the effect of turbulence was sufficiently small to warrant

[3]C.-R. Acad. sci., 140, 232-234 (1905).

TABLE 1

Date of test	Critical potential	Air-flow	Computed mobility
	volts	*cc/second*	*cm/sec/volt/cm*
January 5, 1932	630	1300	0.00048
April 5, 1932	600	1200	0.00046
October 17, 1933	350	700	0.00046
October 18, 1933	350	700	0.00046

neglecting and that one may therefore accept the above computed mobility as real. It would therefore be of interest to subject other mobility-determinations to careful scrutiny in order to determine if a real difference in mobility of large ions takes place from place to place. If any turbulence-effect was present in the apparatus used by Langevin, it would have tended to lower the calculated mobility from his data and to have brought about a difference in the results given in Table 1 and those by Langevin. On the other hand, there may not have been turbulence in his air-flow tube, that is, the difference in mobilities may be real, thus indicating that the particles of which the large ions are composed are not identical in size at the two places of measurement. This indication is of importance and deserves to be followed up by additional experiments at various places over the Earth's surface and under diversified conditions.

Attention has already been called by one of us[4] regarding an apparent difference in character between the diurnal variation for condensation-nuclei and that for the positive large ions. The evidence is strong in favor of the diurnal-variation curve for condensation-nuclei as published being representative for this particular time of the year (March). There are also no grounds for questioning the large-ion diurnal-variation curve, yet it does not seem possible that the two curves can be so much at variance. It is hoped that additional investigational work may assist in clearing up this whole matter.

[4] Terr. Mag., **39**, 65-68 (1934).

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REVIEWS AND ABSTRACTS

(See also pages 102, 119, and 144)

COMITÉ MÉTÉOROLOGIQUE INTERNATIONAL: *Procès-verbaux des séances de De Bilt, 4-7 octobre 1933.* Utrecht, Kemink en Zoon N. V., 1934 133 pp. 24 cm.

The International Meteorological Committee met at De Bilt, Holland, October 4-7, 1933, and the report of the meetings has now been published as No. 17, of the publications of the Secretariat of the International Meteorological Organization.

In all five sessions were held under the presidency of E. van Everdingen, at which twelve members of the Committee and six guests were present. The Agenda called for reports of the presidents of the various commissions and these reports, printed as appendices to the proceedings, occupy about three-fourths of the publication. With the exception of the reports of the International Commission for the Second Polar Year,

1932-33, and of the Commission of Terrestrial Magnetism and Atmospheric Electricity, these communications deal with purely meteorological matters.

In the course of the meetings 17 resolutions were adopted, among which the following are of interest to readers of this Journal:

(8) The Committee appreciates greatly the valuable aid which the Rockefeller Foundation has offered to the International Commission of the Polar Year 1932-33, thanks to which the Commission has been able to complete very advantageously the world network of terrestrial-magnetic and electric stations and to contribute to the study of the upper atmosphere by the use of radiosondes. The Committee is of opinion that the aid from the Foundation will be of great value not only for the Polar-Year work but also for future research.

(9) In order to derive the greatest possible profit, both from the scientific and practical points of view, from the observations made during the Polar Year, the Committee considers it indispensable to charge a central organization with the program of concentration and coordination, which was also recommended at the Lisbon (1933) meeting of the International Association of Terrestrial Magnetism and Electricity, and to render as soon as possible its assistance to institutes and investigators who desire to make use of it. The Committee instructs the International Commission for the Polar Year to pursue this end in the most effective manner and expresses the wish that the funds necessary for this important work be placed at the disposal of the Commission.

(11) The Committee desires again to impress upon all those taking part in the Polar Year the urgent necessity for publishing their observations with the least possible delay. Until the observations are in the hands of scientific workers they cannot commence those investigations whose successful completion can alone justify all the time, energy, and expense which have been devoted to the Polar Year.

(12) The Committee considers it important that there be printed at least 20, if possible 100, separates of publications or periodicals of which the contents belong to the domain of Polar-Year researches, either as data or as discussion. The National Polar-Year commissions, organizations, or institutes should hold these reprints at the disposal of the International Commission of the Polar Year. They shall later be exchanged by the International Commission of the Polar Year with national organizations in order that they may be available to investigators qualified for this work.

In the report on the work of the Commission of Terrestrial Magnetism and Atmospheric Electricity, emphasis was placed on the importance of the continued publication, with the assistance of the Royal Meteorological Institute of the Netherlands, of the "Caractère magnétique de chaque jour" and of the enterprise of publishing the "Caractère magnétique numérique des jours" of which volumes I-V cover the years 1930, 1931, and 1932, and volume VI applies to the first quarter of 1933. This latter publication is issued at the expense of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics and is distributed together with the "Caractère magnétique de chaque jour" by the Secretariat of the International Meteorological Organization.

The interest of the Commission of Terrestrial Magnetism and Atmospheric Electricity was also manifested in the fact that the International Commission for the Polar Year possesses a considerable number of magnetic and electric instruments which can be supplied on loan to magnetic stations and institutions for future research, particularly in view of the possibility that, when the activities of the International Committee for the Polar Year are finished, the Committee may derive advantage from this property.

The report of the President of the International Commission of the Polar Year 1932-1933, covered the activities of the Commission since the meeting at Locarno in 1931 and indicated the proposed work in the future. In this connection the importance was indicated of certain resolutions adopted by the Commission at previous meetings. Now that the Polar Year is ended, the Commission is turning its attention to the accomplishment of two special objectives, namely, to act as a central organization for obtaining the greatest possible return from the work done during the Polar Year at enormous expense, effort, and sacrifice, and to ensure that the material which is the property of the Commission (magnetic, electric, and aerological instruments) will serve in the future to advance the science of geophysics.   H. D. Harradon

RECENT RESEARCHES ON FLUCTUATIONS OF COSMIC-RAY IONIZATION

By James W. Broxon

During the period since the detection of a natural, very penetrating, so-called cosmic radiation soon after the discovery of radioactivity, there have been many investigations of the fluctuations of the ionization produced presumably by this radiation. In general, these have not been of an exhaustive nature, and throughout the history of the investigations the results have been conflicting in many details. In particular, there has not been general agreement regarding the peculiarly interesting question as to whether the fluctuations provide evidence of regular variations of the penetrating-radiation intensity with time. At present there appears a tendency toward the conclusion that such variations, if they exist, are very small and perhaps produced by terrestrial conditions.

The methods of measurement have in many instances been considerably refined, and certain of the fluctuations have been shown to depend upon the conditions of measurement. An important instance of this was the demonstration by Erikson[1] and others[2] that the ionization-current produced in a high-pressure ionization-chamber by a particular radiation-intensity is a function of the temperature of the gas.

Atmospheric conditions have also been found to have an effect. Myssowski and Tuwim[3] detected a significant dependence of the cosmic-ray ionization upon barometric pressure, and Messerschmidt[4] observed a relation with atmospheric temperature.

In view of the more recent developments, the writer decided to investigate the cosmic-ray ionization-fluctuations in relation to time and as many of the atmospheric conditions as could readily be determined. The ionization was measured in a 13.8-liter chamber containing air at a pressure of 157.5 atmospheres (17°.4 C) and surrounded by a water-shield nearly six feet thick, located in the basement of a stone building at Boulder, altitude 5400 feet, latitude 40° north. A null method of measurement eliminated several possibilities of disturbance. With the aid of G. T. Merideth and L. Strait, observations were made at 4-hour intervals for 15 consecutive days, April 6-20, 1932. Each observation consisted of three 8½-minute readings made during a period of one hour. Records of the atmospheric potential-gradient, the barometric pressure, and the relative humidity and temperature of the outdoor air were obtained from recording equipment.

As reported elsewhere,[5] when the hourly ionization-values were plotted in turn against the corresponding values of barometric pressure, atmospheric potential gradient, outdoor temperature, and absolute humidity of the free atmosphere, apparently random distributions were obtained excepting in the case of the barometric pressure. A decrease of 2.1 per cent in ionization corresponded with an increase of one cm in the barometric column.

No regular diurnal variation of the ionization was observed, either before or after reduction to a common barometric pressure.

[1]H. A. Erikson, Phys. Rev., **27**, 473-491 (1908).
[2]A. H. Compton, R. D. Bennett, and J. C. Stearns, Phys. Rev., **39**, 873-882 (1932); K. Wolff, Zs. Physik, **75**, 570-574 (1932); J. W. Hake, Univ. Kansas Sci. Bull., **20**, 183-197 (1932); J. W. Broxon, Phys. Rev., **40**, 1022-1023 (1932), and **42**, 321-335 (1932).
[3]L. Myssowsky and L. Tuwim, Zs. Physik, **39**, 146-150 (1926).
[4]W. Messerschmidt, Zs. Physik, **78**, 668-689 (1932), and Physik. Zs., **33**, 233-234 (1932).
[5]J. W. Broxon, G. T. Merideth and L. Strait, Phys. Rev., **43**, 687-694 (1933).

In agreement with others, an occasional, sudden, large increase of ionization was observed at intervals of several hours of observation-time.

As Gunn[6] had suggested, it was to be expected that cosmic-ray fluctuations might accompany terrestrial-magnetic fluctuations, in view of the latitude-effects observed by Clay,[7] Compton,[8] and others. At the suggestion of E. O. Hulburt it was decided to compare the cosmic-ray data with the magnetic data available. Since only magnetic character-values were at hand, it appeared to the writer that they might best be compared with values of a similar function of the ionization. Accordingly, the product of the average by the difference between the extremes of the six hourly ionization-values (corrected for barometric pressure) for a particular day was evaluated and designated the cosmic-ray ionization "character" for that day. As shown in Figure 1 (taken from Fig. 1 of our report[9]), there were readily noticeable similarities between the cosmic-ray "character"-curve for the 15-day period, and the corresponding world-wide magnetic character-curve. In some respects there was a closer resemblance with the magnetic character-curve for the station at Tucson, some 600 miles distant.

In view of this correspondence, it occurred to the writer that this treatment might bring out relations with other variables not otherwise apparent. Accordingly, a "character"-function was formed for each of the other measured quantities, only the values of these at the times of the ionization-measurements being employed. Only in the case of the
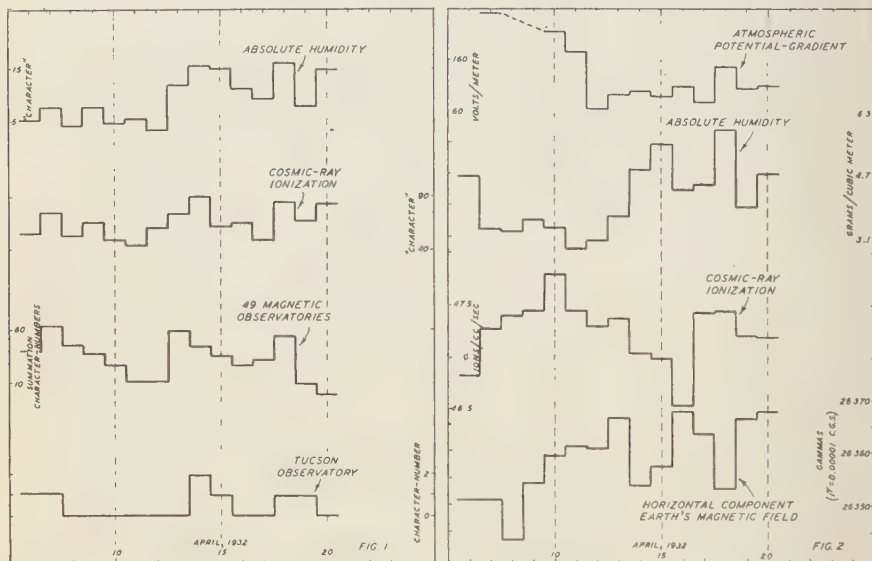
FIG. 1—FLUCTUATIONS IN CHARACTER OF ABSOLUTE HUMIDITY, COSMIC-RAY IONIZATION, AND MAGNETISM, DURING FIFTEEN-DAY PERIOD, APRIL 6-20, 1932 — FIG. 2—FLUCTUATIONS IN ABSOLUTE HUMIDITY, COSMIC-RAY IONIZATION, AND HORIZONTAL COMPONENT EARTH'S MAGNETIC FIELD (VALUES H AT TUCSON CORRECTED TO ACTUAL TIMES OBSERVATIONS IONIZATION)

[6] R. Gunn, Phys. Rev., **41**, 683 (1932).

[7] J. Clay, Proc. K. Akad. Wet., Amsterdam, **31**, 1091-1097 (1928), **33**, 711-718 (1930), and **35**, 1282-1290 (1932); only the last of these read.

[8] A. H. Compton, Phys. Rev., **41**, 111-113 (1932).

atmospheric potential-gradient and the absolute humidity was an appreciable correspondence apparent. As shown in Figure 1, there is a decided similarity between the ionization "character"-curve and the absolute-humidity "character"-curve. The Pearson coefficient of correlation for these two is 0.76 ± 0.07. The coefficient of correlation between the ionization "character" and the world-wide magnetic character-curves is 0.30 ± 0.16. The large probable error results from the small number of readings employed in the establishment of this rather low correlation-coefficient. In view of certain features of the curves, however, particularly in regard to the Tucson values, and the fact that in comparing the cosmic-ray "character" with the magnetic character no correction was made for the apparent considerable influence of the humidity, it is considered that the correlation in this instance is significant.

In Figure 2* (partly Fig. 2 of our report[9]), there are shown mean-of-day values of the atmospheric potential-gradient, cosmic-ray ionization, and absolute humidity. [In an attempt to determine a function of the cosmic-ray ionization observations analogous to the magnetic character of days, the average of the values (generally six) for a particular day was multiplied by the difference between the greatest and the least of the values for that day. This product will be referred to as the cosmic-ray ionization "character" of the day.] As we pointed out, there is a noticeable inverse correspondence between the ionization- and humidity-curves during the first ten days, and when the averages during this period were compared, a decrease of 0.5 per cent in the ionization was found to accompany an increase of one gm per cubic meter in the absolute humidity. The correlation-coefficient between the two curves of averages *for this 10-day period* is found to be -0.75 ± 0.09.

Copies of the magnetograph-records from the Tucson Station during the period of our observations have now been supplied by the United States Coast and Geodetic Survey. In Figure 2 average values (only values corresponding to the actual times of observation of the ionization were used) of the horizontal component of the terrestrial magnetic field at Tucson are also shown together with our ionization- and absolute-humidity values. There is no general relation apparent, but during the last seven days, including the period when there is not good correspondence with the humidity, there is some indication of an inverse correlation between the ionization and the magnetic field-intensity. The correlation-coefficient for the two *during this period* is -0.31 ± 0.23, the very large probable error indicating that little or no significance can be attached in view of the very short period.

Almost immediately following our report there appeared reports of European researches which provide further evidence of the influence of atmospheric humidity and terrestrial magnetism upon cosmic-ray ionization.

Steinmaurer and Graziadei,[10] continuing a report by Hess and Steinmaurer[11] of the measurements being carried on at the cosmic-ray observatory on the Hafelekar at Innsbruck, Austria, altitude 2300 meters, latitude 47° north, have shown a dependence of the cosmic-ray ioniza-

*The indicated values for potential gradient should be divided by 2.35 to get true volts per meter.
[9]J. W. Broxon, G. T. Merideth, and L. Strait, Phys. Rev., **44**, 253-257 (1933).
[10]R. Steinmaurer and H. Graziadei, Berlin, SitzBer. Akad. Wiss., No. 22, 672-685 (1933).
[11]V. F. Hess and R. Steinmaurer, Berlin, SitzBer. Akad. Wiss., No. 15, 521-542 (1933).

tion upon the atmospheric humidity, the cloudiness of the sky, and the outdoor temperature. With their 22.6-liter ionization-chamber containing CO_2 at 9.5 atmospheres and surrounded by a 10-cm lead-shield, they were able, with the wealth of data provided by their continuous records, to establish a definite decrease of the ionization accompanying an increase of either the absolute humidity, the cloudiness, or the outdoor temperature. These three effects they consider actually to be only different aspects of the primary effect of the water-content of the atmosphere.

With the arrangement described a decrease of ionization of a little less than 0.2 per cent was found by them to accompany an increase of one gm per cubic meter in the absolute humidity. It is perhaps surprising that this should be at all comparable with the value found by us on the basis of our averages for the first ten days of observation. Even their value they regard as considerably too large on the basis of any reasonable assumptions as to the aqueous vapor-content of the atmosphere, and the absorption-coefficient of radiation capable of penetrating even the shield they employed. They established from the slopes of their experimental curves, however, that $\triangle U/\triangle \theta = (\triangle U/\triangle F)$ $(\triangle F/\triangle \theta)$, approximately, where U represents the cosmic-ray ionization intensity, θ the outdoor temperature, and F the absolute humidity.

With less shielding, the dependence of the ionization upon the three variables was considerably different. This they explain in terms of a combination of absorption and production of subsidiary radiations.

With the upper portion of their shield removed, Steinmaurer and Graziadei found a dependence upon sunshine-intensity which did not exist with the full shield. They also observed effects due to snowfall.

Whereas Freytag[12] recently concluded upon analysis of Lindholm's[13] data that diurnal variations of the harder components of the cosmic radiation-intensity are the more marked the greater the sunspot-activity, Hess[14] and Steinmaurer and Graziadei[10] found no such effect. They did find some indications of a slight increase of the ionization ten or fifteen days after the passage of large spots through the central meridian of the Sun.

They also observed that a slight decrease of the ionization usually (but not always) accompanied magnetic storms. This they considered in contradiction with the observations of Corlin[15] at Abisko, Sweden, latitude 68° 21′ north. Corlin[16] has very recently announced, however, that whereas his earlier observations during 1929-30 show an *increase* in ionization during aurorae and magnetic disturbances, his observations during 1932-33 show a *decrease* in the ionization under similar circumstances, and he considers that the Hafelekar data show a similar change in the effect between the two periods. He associates the change in the effect with the contemporary progression in the sense from sunspot-maximum to sunspot-minimum.

As is shown by the diagrams mentioned above, there seems to be no

[12]O. Freytag, Beitr. Geophysik, **39**, 10-11 (1933).
[13]F. Lindholm, Beitr. Geophysik, **26**, 416-439 (1930), and **35**, 224-229 (1932).
[14]V. F. Hess and R. Steinmaurer, Nature, **132**, 601-602 (1933).
[15]A. Corlin, Lund Obs. Cir. No. 1, 1931—not available to the writer. It was indicated in a research item—Nature, **130**, 245 (1932)—that *no* auroral effect had been found at Abisko.
[16]A. Corlin, Nature, **133**, 24-25 (1934).

relation between our cosmic-ray ionization average values and the magnetic character-values.

Messerschmidt,[17] working at Halle, Germany, latitude 51°.5 north, has also found some evidence of a magnetic effect upon the cosmic-ray ionization. For data obtained during the period from April 14 to June 29, 1931, he found an inverse relation between the average ionization in a chamber shielded with 10 cm of lead, and the horizontal component of the terrestrial-magnetic field-intensity, the relation being striking during the period, May 20-30. No such relation between hourly values was observed. With a 20-cm lead shield, during winter months, the effect was not observed.

Regener[18] has also associated high ionization-intensity values recorded at altitudes above fifteen kilometers during the balloon-ascent of March 29, 1933, with magnetic disturbances occurring during that day. His assumption that the additional intensity at these heights, not observable lower, may have been due to a sunspot, has been supported (according to a note he has kindly supplied) by information that ". . . on the 28th of March, one day before the fourth ascent, a remarkable sunspot was passing through the central meridian of the Sun, whilst on the other three days (on which ascents were made— J. W. B.) no sunspot was to be seen in the central part of the Sun."

It appears that the findings of the last year have already provided rather convincing evidence for the existence of influences upon the cosmic radiation due to water-content of the atmosphere and to terrestrial-magnetic disturbances. Clarification of these may be expected to be provided by long-continued, continuous observations, and cooperation of observers on a world-wide scale.

[17]W. Messerschmidt, Zs. Physik, **85**, 332-335 (1933).
[18]E. Regener, Nature, **132**, 696-698 (1933), and Physik. Zs., **34**, 820-823 (1933).

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NOTES
(See also page 132)

11. *German participation in foreign Polar-Year expeditions*—Although unfavorable financial conditions prevented the establishment of a German official Polar-Year station, German participation in the Polar-Year enterprise through cooperation with other countries in a number of expeditions was found possible. A summary of this participatory work is given by Dr. P. Heidke in the November-December number of the Annalen der Hydrographie und Maritimen Meteorologie, from which the following notes are extracted.

Hooker Island –Dr. J. Scholz, at the invitation of the Soviet Government, took part in the expedition to Hooker Island, Franz Josef Land. He was engaged chiefly in making atmospheric-electric measurements simultaneously and by the same method as those at Potsdam, thus making possible a comparison of the results obtained near the North Pole with those in Northern Germany.

Novaya Zemlya—Dr. K. Woelken, accompanied, as geophysicist, the Russian expedition under M. M. Yermolayev. His special work consisted in glaciological observations and the investigation of the propagation of sound by exploding dynamite in and on the ice.

Tromsö—Dr. W. Bauer continued his investigatorial work on the aurora at Tromsö in Northern Norway. He gave attention principally to (1) photographic questions as to materials, methods, objectives, etc., suitable for auroral work, (2) improvement of color-photography and of instantaneous photographs for the purpose of fixing, in rapidly-changing displays, the finer differences of structure, (3) cinematographical

photography, (4) altitude-determinations, and (5) registration of auroral intensity. Dr. A. C. Kreielsheimer, of the Heinrich-Herz-Gesellschaft, was also at Tromsö making investigations of special interest to radiotelegraphy.

Julianehaab, Southwest Greenland—Dr. G. Baumann spent the late spring and early summer of 1933 at the Italian station at Julianehaab engaged chiefly in making meteorological observations.

12. *Polar-Year records, College-Fairbanks Station*—The Polar-Year records obtained at the College-Fairbanks station in terrestrial magnetism and atmospheric electricity are now being duplicated by the United States Coast and Geodetic Survey in order that copies may be available both at the headquarters of the Polar-Year Commission in Copenhagen and in Washington, where the records will be kept available for use by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington and by the Coast and Geodetic Survey. Good progress is being made in the study of the magnetic records at the Survey and of the atmospheric-electric and earth-current records at the Department.

13. *Auroral work at College, Alaska*—Professor Veryl R. Fuller, in charge of the auroral work at College, Alaska, reports that during the month of February 1934, a considerable number of auroral photographs was taken—on two nights alone over a hundred exposures were made.

14. *Secular-variation work in United States*—R. G. Ambrose has discontinued field-work in the western and southwestern states. During the present season Chester Campbell and S. A. Deel will have parties in the western states and George O. Weber is now at work in the northeastern part of the country, so that it is expected that by the end of the present calendar year most of the information required for the preparation of the isomagnetic map for 1935 will be available. Repeat magnetic observations will be made in the Aleutian Islands during the coming season by a party of the Steamer *Surveyor*.

15. *Rebuilding at Cheltenham Magnetic Observatory*—The Variation-Building of the Cheltenham Magnetic Observatory at Cheltenham, Maryland, which was built in 1900, was found during 1933 to be badly infested with termites which had destroyed part of the wood-grill foundation and were actively at work in other parts. The building as originally designed and the first successful above-ground structure for constant-temperature requirements of a magnetic observatory, has four feet of sawdust between the outer walls and two feet of sawdust between the walls of the inner rooms. The wood grillage of heavy timbers above the stone foundation has been completely reconstructed with every precaution to eliminate all future danger from termites, which in later years have infested the region of Maryland. The foundation now consists of cement-block walls extending several feet from the ground at the top of which a wide copper plate is installed which the insects are unable to pass. Additional precautions were taken by treating the ground beneath the building with a mixture of creosote and kerosene as advised by Bureau of Entomology of the Department of Agriculture. A layer of concrete several inches think was then placed over the entire area covered by the building and, in view of possible cracks, the whole was covered with a layer of tar. It is believed that with these precautions the building, though now nearly 35 years old, will have a long extension of life. The new construction was made especially necessary by the placing of a new roof of rather heavy construction several years ago. During the rebuilding the Observatory was wired so that electric lights can be used in the variometer-room and a pier was placed for a la-Cour insensitive variometer.

Naturally work of this character disturbed the Eschenhagen and Adie magnetographs which however were not removed from their piers. Loss of important records, which would have been especially serious because the Polar-Year program was still in progress in the Southern Hemisphere, was prevented by the loan of a la-Cour magnetograph by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. This has been operated in the comparison-and-test building which made that building unavailable for other work during the period but this caused no inconvenience since no other special work was scheduled which could not be postponed.

It was decided that, in view of information regarding the termite-activities obtained during these repairs, the precautions taken in the case of the office-building recently rebuilt and of the recently built comparison-and-test building were insufficient. Accordingly, some ground was excavated from beneath these buildings and the same method followed, that is, by treating the ground and by laying concrete covered with tar over the whole areas occupied by the two buildings. If other observatories have similar difficulties and desire more detail the Coast and Geodetic Survey will be glad to furnish additional information on application.

SOME COMMENTS UPON APPLIED GEOPHYSICS IN THE PAST YEAR, 1933[1]

By F. W. Lee[2]

The material for this article has been kindly furnished the writer by our colleagues in geophysics. Unfortunately it was impossible, due to limitations of space, to print all the comments. The writer hereby again wishes to thank these correspondents for their interest in making this review possible. Because of the papers already published by Dr. E. DeGolyer and Sherwin Kelly in the January issue of the Transactions of the Institute of Mining and Metallurgical Engineers references to them have been omitted or greatly abridged.

Dr. Arnaldo Belluigi reports from Italy the use of resistivity-methods to a depth of 2000 meters, using Wenner's method. The results were generally good. He employed automatic photographic registration in the field. He has done theoretical work upon the influence of the n-th stratum or bed.

A communication from Professor J. Koenigsberger mentions the extended use of the various resistivity-methods. He brings to our attention a very valuable supplementary method, which also measures resistivity in another way. This method uses the induction-principle and measures the induced currents in the various beds. Here the diameter of a coil is varied proportional to the depth of penetration. The coil is energized with alternating current of frequency low enough to avoid skin-effects. The circuits are so connected that only the reaction of the ground is registered. The electrical induction in the various beds changes, and the number of changes is an indication of the number of beds traversed as the coil is increased gradually in diameter. The apparent resistivity, as developed by W. Nunier, is $P = (8.3 \times 10^{-9} f R I) / H_z$, where f is the frequency, R the radius of the coil, I the current in the coil, and H_z the vertical magnetic field-component of the ground reaction.

The usual surface-resistivity methods are more exact the larger the resistivities, especially at the lesser electrode-spacings. The above induction-methods are more sensitive with larger loops and lower resistivity. In depths of 3 to 450 meters over a known profile eight separate beds were identified, using a combination of the two resistivity-methods.

Dr. D. C. Barton states that very active use of routine geophysical methods, with little advance in technique, prevails in oils work. The torsion-balance and the seismic methods are relied upon chiefly. The pendulum-methods have found a keen competitor in the "Gravitometer" and a large company has been relying wholly upon it. Aerial maps determine the position and the altitude-meters the elevation of the stations.

The Cleveland oil-field may be spoken of as a pendulum-field, although drilling had determined it as a structural high for a year or more. Most reflection-shooting has been the detailing of prospects, although

some companies have done systematic reflection-mapping upon the Conroe Trend.

The electrical logging of wells by the Schlumberger methods, using resistivity and diffusion-potentials for determining oil-sands, has become routine practice with several oil companies.

The gravitometers generally rely upon the work of gravity against a spring. Three different types have been developed by the Humble Oil Company. Dr. Trueman's gravitometer, when checked against a pendulum and torsion-balance survey, has proved of equal accuracy. He has completed important quantitative calculations for determining overhang of salt-domes from torsion-balance observations. Tomball in Harris County, a torsion-balance minimum which showed also some high speeds and was also reflected, proved to be a good geophysical dome with only comparatively shallow thicknesses of sands. Commercially, therefore, Tomball is not an important discovery.

Dr. W. P. Jenny points to the fact that none of the various methods so far developed is a panacea for finding structures. The possibilities of the torsion-balance, pendulum, reflection, and refraction methods are outlined fairly well. The limitations of the electrical methods have not been defined so distinctly. Magnetometer-methods also hold possibilities for the future. It is at present not a question of methods so much as of finding the proper one for the geology in question.

Contrary to expectations, glacial drift in Michigan and Canada does not impede magnetic prospecting. Even in the Gulf Coast magnetic anomalies assist in interpreting other geophysical data.

The torsion-balance has regained much of the ground lost to the reflection-method, especially in the Gulf-Coast Plane. The pendulum has replaced the torsion-balance to some extent in the hilly parts, as, for example, in the Conroe Trend.

In a recent comparison of an extended survey by the Trueman gravitometer with one by the torsion-balance, conclusions would indicate that the gravitometer does not entirely satisfy the requirements of the Gulf-Coast Area.

The considerable number of dry holes on reflection-prospecting in the Gulf-Coast Area has in some instances strongly shaken faith in reflection- and dip-shooting. However, outstanding successes have been achieved by this method in the Oklahoma and central Texas districts; but close study of surface and subsurface geology is indespensable for correct interpretation of the reflection-data even there.

The main progress in the practical application of geophysics rests in the steadily growing tendency to confine the conclusions drawn to two or three different methods for final interpretation.

Dr. C. E. Van Orstrand has studied the correlation between natural rock-temperatures and the mineral-content of the formations in the Michigan copper district. He used a new mercury thermometer developed by Professor L. R. Ingersoll of the University of Wisconsin. The observed temperatures fall upon a smooth curve, with a well-defined convexity toward the depth-axis. Upon the premise that the curvature is due to a rise in temperatures since the ice-ages it is found that 30,000 years may have elapsed since the ice-age disappeared. The reciprocal of the temperature-gradient at an average depth of 4500 feet is 1°F in 103.1 feet (1°C in 56.6 m).

The following are some of the results of temperature-investigations:

In the Stalin district, Donetz Basin, Russia, the temperature in two wells indicates 91.5 to 76.3 feet per 1°F.

Oil-fields in the Apsheron Peninsula, Bibe Eibat, 1°F in 57.5 feet; Smakham, 1°F in 47 feet.

Electrical resistance-thermometers used by R. H. Cleland in measuring the deep mines in northern Ontario, Canada, show: Porcupine district at 3065-3895 feet, 1°F in 164 feet to 1°F in 233.2 feet. Kirkland Lake District between 2993 and 4905 feet, 118.4 to 167.1 feet per 1°F. In the Sudbury District to depths of 3100 feet, 1°F in 155.2 feet.

From a series of observations at Grass Valley, California, in a gold mine to 3400 feet it is 1°F in 189.8 feet.

Dr. D. Chahnazaroff has made a number of comparisons of the various methods of determining the temperature in wells and drill-holes, maximum and open-cut thermometers have an accuracy of $1/3$°C, registering thermometers 1°C, and thermoelectric thermometers 0°.1C. Work upon the problem concerning the genetic relation of oil- and water-emulsions and the dynamic phenomena in the various beds indicate that there is not only a paragenesis between them but that the water also plays a geochemical rôle still unknown. His study of the physics which accompanies penetration of gas through rocks forces him to the conclusions that the distributions of gas are due to geological disloca-tions rather than to penetration of the gas through the beds. It there-fore introduces the geophysical study of geologic faulting and zonal dislocation in subterranean gas-districts.

Dr. H. Shaw of the Kensington Museum, London, has sent the following communication from Great Britain:

"At the Imperial College of Science and Technology, Professor A. O. Rankine, who has been engaged in the construction of a mag-netic gradiometer capable of measuring small distortions of the Earth's magnetic field, has produced a very sensitive instrument. This instrument is capable of demonstrating in a very convincing manner, the paramagnetism and diamagnetism of substances of small susceptibility (for example, water and gases), even under small magnetic fields. The instrument takes the form of a torsion-balance, from the ends of which two metallic cylinders of similar weight and dimensions are suspended, each with its axis vertical. One of these is a very strong magnet, while the other (which is merely a counter-poise) is non-magnetic.

"Bruckshaw, working in the same Laboratory, has produced a modification of the Bieler-Watson apparatus, and has succeeded in eliminating some of the serious disadvantages which the original apparatus possessed.

"Evershed and Vignoles have introduced a special low-range earth-tester for geophysical surveying by the earth-resistivity method. With this instrument the effect of all electrode-resistances is en-tirely eliminated.

"*International Geophysical Prospecting Company, Limited*—As compared with 1932, when this Company was mainly active in the

Permian Salt Basin of northwest Germany, the year has been notable for the number of countries in which this Company has either undertaken or directed geophysical surveys and investigations, for example, Austria, Rumania, the British Isles, and Trinidad, British West Indies.   The torsion-balance and magnetic methods have been principally employed in connection with these surveys, which for the most part were made upon the behalf of British and American oil companies.   Attention has also been given to increasing the efficiency and the reliability of certain instruments, the 'Watts magnetic variometer,' in which the irregular responses arising from temperature-changes have been greatly reduced, and an improved optical system fitted.

"*Applied Geophysics, Limited*—This Company has carried out surveys on behalf of British and American oil companies in Germany, and is at present interested in the application of the seismic reflection-method to gold mining in Africa.   It has also been engaged in the development of an electrochemical method and has tested the possibilities of electrical resistivity-methods in connection with water-supply problems."

Dr. B. Gutenberg writes from Pasadena, California, that the situation this year does not differ much from that of a year ago.   There have been no major new results, but improvements have been made in many respects.   He makes the following comments: *Geodesy*—The idea of gradual movements going on all the time to a much greater extent than has been believed, has been advanced.   The recent data concerning the distance Greenland to Europe have not yet been published.   *Gravity*— Many publications on undulations and isostasy have appeared, but no final solution.   *Applied methods* Nothing new has developed in applied methods, as far as can be observed.   *Magnetism* Many investigations have been made or are under way, but no important results have been announced.   *Seismology*—Among seismological developments are: New proof concerning deep-focus earthquakes; revised travel-time curves and revised depths of discontinuities; additional data on wave-velocities and development of the reflection-method (the refraction-method seems to change more and more to a supplementary method of the preceding); no new fundamental results.   *Structure of the Earth*— New discussions are in progress on the questions (1) as to whether the crystalline material is confined to the uppermost 50 miles and (2) as to whether the core transmits transverse waves.   There are as yet no final results on either question.   *Oceans, hydrology*—Gradual progress is reported, but nothing new of general importance.   *Meteorology*—There has been further development of the air-mass analysis.   The modern ideas are being considered more in the United States than before. Many papers on long-range forecast have appeared with slow progress.   *Bodily tides of the Earth*—Investigations have continued with promising, but no final, results.   *Geothermics and electric methods* –Development of these methods show not very much progress.

Dr. L. B. Slichter makes the following observations: *Great significance of unique and general or non-unique solutions of geophysical data* –The quality of uniqueness depends largely upon geologic bedding.   The induction-methods, when applied to horizontal bedding, also yield results

concerning the resistivity and dielectric constant of the material with depth. By using large powers and intervals of the order of 50 miles, large-scale resistivity-measurements were made. Potential measurements were made to distances of 100 miles. The chief gain here was largely perfection of operating technique.

Dr. L. V. King, of McGill University, in an interview developed some very interesting mathematical relations in the three-layer resistivity depth-determinations, especially the depth of the second layer. By selecting measurements carefully this depth can be determined without the tedious work of superposition-methods. The similarity between the resistivity-formula and that of radiation from wireless antennas is very striking. The transient in the center of the loop when energized by direct current should furnish valuable information concerning the stratification underlying this loop.

From a mimeographed report by R. C. Schappler and F. C. Farnham of the Missouri Highway Commission the results of resistivity-determinations have achieved a large saving in rock excavation in highway programs. It was found that in two consecutive years before and after such methods were used, the error dropped from 25 to 3 per cent.

Dr. Karl Sunberg and H. Hedström, working upon prospecting for oil in Rumania, add that a new method of correcting for topography has been developed. The basis for the method is to observe readings at two or more frequencies and base the interpretations upon the vector-differences. In this manner depth-penetrations have been increased to 2500 feet.

From Timmins, Ontario, Dr. H. Lundberg advises that very good results have been obtained in the Porcupine District with the "Racom" methods. The details of this work are published in the Canadian Mining Journal.

O. H. Gish of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington informs us that the outstanding discovery of the year was made by Dr. T. H. Johnson, who showed that a large part of all primary radiation consists of positive corpuscles, where heretofore these corpuscles were considered negative.

Much interesting work was done by Dr. C. A. Heiland and by Dr. I. Roman, with their respective organizations.

U. S. BUREAU OF MINES,
  Washington, D. C.

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NOTES

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16. *International Congress of Electro-Radio-Biology*—For the purpose of instituting among physicists, chemists, biologists, naturalists, and others, close and profitable collaboration indispensable for the advancement of radio-biology, not considered as a branch of radiology or of biology, but as a separate science in itself, the International Society of Radio-Biology is now making arrangements for the First International Congress of Electro-Radio-Biology which will be held at Venice, in the Ducal Palace, in September 1934, under the presidency of H. E. Count Volpi di Misurata, Minister of State. Those desiring detailed information are invited to apply to the temporary head-office of the International Society of Radio-Biology, addressing their correspondence to Dr. Giacondo Protti, S. Gregorio 173, Canal Grande, Venice, Italy.

17. *Errata*—The following corrections are to be made in the March 1934 number of the JOURNAL. On page 11 Figure 4 should be turned 180°; on page 35 in first line for "and" read "und"; on page 36 in second line following equation (1) for "$T = 0$" read "$T_1 = 0$"; on page 37 in sixteenth line for "genaue" read "genau"; on page 39 in Tabelle 2 in row of mean values for "40" read "39" and for "2.9" read "2.7"; on page 42 in second line following Tabelle 5 for "höchsten und darauffolgenden" read "höchstem und darauffolgendem"; on page 45 in tenth line of second paragraph for "dieser" read "diese" and in eleventh line of third paragraph omit comma following "grossen."

18. *Bell Telephone Laboratories*—The Department of Development and Research of the American Telephone and Telegraph Company was merged with the Bell Telephone Laboratories, Incorporated, effective March 1, 1934. All their activities are now carried on under the corporate name of Bell Telephone Laboratories under the direction of Dr. F. B. Jewett.

19. *Personalia*—The Keith Prize for the period 1931 to 1933 has been awarded by the Council of the Royal Society of Edinburgh to Dr. *A. Crichton Mitchell*, for his work on "The diurnal incidence of disturbance in the terrestrial magnetic field."

Dr. *J. P. van der Stok*, Director of the Section of Oceanography and Marine Meteorology of the Royal Meteorological Institute of the Netherlands from 1899 to 1923, and formerly Director of the Magnetical and Meteorological Observatory at Batavia, died March 29, 1934, aged 83 years.

Professor *Demetrius Eginitis*, Director of the National Observatory and Professor of Astronomy at the University of Athens, and formerly president of the Greek National Committee of Geodesy and Geophysics, died on March 14, 1934, at the age of 71 years.

Dr. *Paul L. Mercanton*, Professor of Meteorology at the University of Lausanne, has been appointed Director of the Schweizerische Meteorologische Zentralanstalt in Zürich.

Dr. *R. Madwar* has been appointed Director of the Helwan Observatory in place of *P. A. Curry*, who is now Deputy Director General of the Physical Department, Egypt.

Dr. *B. J. F. Schonland*, Senior Lecturer in Physics, University of Capetown, South Africa, and well known for his investigations of lightning, arrived in New York on April 8, 1934, for a ten-week visit in the United States. He spent the first six weeks at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. While in Washington he presented papers on the results of some of his recent work before the scientific meetings which were held in Washington the latter part of April. Before his departure in June to take up work through January 1935 at the Cavendish Laboratory, he will visit a number of universities and scientific institutions in the eastern and middle-western states.

Dartmouth College on June 18, 1934, conferred the honorary degree of Doctor of Science on Dr. *John A. Fleming*, Acting Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

FINAL RELATIVE SUNSPOT-NUMBERS FOR 1933

By W. Brunner

The following Tables contain the final sunspot-numbers for 1933, for the whole disc of the Sun, based on observations made at the Zürich Observatory, supplemented by series furnished by other cooperating observatories for days (indicated by asterisks) where no observations were possible at Zürich.

Table 1 gives the yearly means of the relative numbers, R, since the last minimum 1923 and the number of days without spots.

TABLE 1—*Yearly means of relative sunspot-numbers, R*

Year	R	Increase	No. spotless days
1923	5.8	......	200
1924	16.7	+10.9	116
1925	44.3	+27.6	29
1926	63.9	+19.6	2
1927	69.0	+ 5.1	0
1928	77.8	+ 8.8	0
1929	65.0	−12.8	0
1930	35.7	−29.3	3
1931	21.2	−14.5	43
1932	11.1	−10.1	108
1933	5.7	− 5.4	240
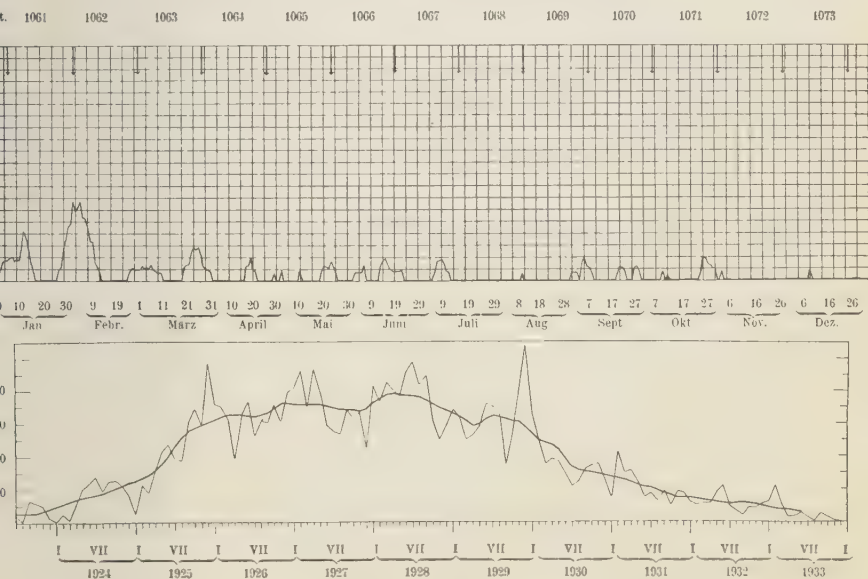
FIGS. 1 AND 2

Figure 1 gives a graphical representation of the daily relative sunspot-numbers for 1933, the times being plotted as abscissas and the relative numbers as ordinates. The limits of the successive solar rotations are

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TABLE 2—*Final relative sunspot-numbers for the whole disc of the Sun for 1933*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	0	45^{ad}	10	9	0	0	0	0	0	0	10	0
2	0	48*	10	8	8	7	0	0	7	0	0	0
3	8^d	67	10	0	0	7	0	0	7	0	0	0
4	15	59*	13	0	0	7	0	0	7	0	8	0
5	17	62^a	11	0	0	7	0	0	0	0	0	0
6	17	67^b	11^a	0	0	14	7	0	M15^c	0	0	0
7	19	53^b	11	0	0	2	17	0	19	0	0	0
8	20*	53	14*	0	0	0	17	0	12	0	0	0
9	16^{a*}	47	9	0	3	0	18	0	11	0*	0	0
10	18^a	33	8	0	8	0	14	0	7	8	0*	0
11	17	33*	7	0	0	0	8	0	0	0	0	8
12	M26^c	16	7	0	0	0	7	7	0	2*	0	0
13	42	11	0	0	0	E12^c	0	0	0	0*	0*	0
14	36	8	0	0	0	16	0	0	0	0	0	0
15	27	0	0	0	0	19	0	0	0	0	0	0*
16	14	0	0	0	0	14	0	0	0	0	0	0
17	7	0	0	E13^c	0*	10	0	0	0	0	0	0
18	0	0	0	13	0	8	0	0	0	0	0	0
19	0*	0	0	20^a	8	8	0	0	0*	0	0	0
20	0	0	0	10	12	8	0	0	0	0	0	0
21	0	0	0	8	12	8	0	0	7	0	0	0
22	0	0	12^d	0	11	9*	0	0	11*	0	0*	0
23	0	0	14	0	17	0	0	0	11	0	0	0
24	0	0	14	0	12	0	0	0	8	0	0*	0
25	0	0	M24^c	0	8	0	0	0	0	0	0*	0
26	0	0	29	0	0	0	0	0	0	M 7^c	0	0
27	0	8	26	0	0*	0	0	0	0	20	0	0
28	E 9^c	11^d	28^a	0	0	0	0	0	11	19	0	0
29	12		22	7	0*	0	0	0	12	14	0	0
30	25*		13	0	0	0	0	0	8	13	0	0
31	35^a		10		0		0	0		10		0
Mean	12.3	22.2	10.1	2.9	3.2	5.2	2.8	0.2	5.1	3.0	0.6	0.3

^{a}Passage of an average-sized group through the central meridian.
^{b}Passage of a large group or spot through the central meridian.
^{c}New formation of a centre of activity: E on the eastern part of the Sun's disc; W on the western part; M in the central circle zone.
^{d}Entrance of a large or average-sized centre of activity on the east limb.

indicated by vertical arrows in the upper edge of the Figure. The secondary maxima and minima succeeding the rotation-periods do not represent real fluctuations in sunspot-activity, but are rather to be attributed to the influence of solar rotation, to a certain stability of the centers of activity for spots, and to the special distribution of these centers of activity in the direction of rotation.

Figure 2 shows the observed and smoothed monthly relative numbers for 1923 to 1933 (1923 year of the last sunspot-minimum). The purpose of smoothing is to eliminate the secondary variations. The method of smoothing is as follows: For obtaining the mean of the epoch July 1, the average of the monthly means of the twelve months January to December is taken (m_1), and for the epoch August 1, the average of the monthly means for February to January (m_2). The mean of these, $m = (m_1 + m_2)/2$, which represents the smoothed relative number for the middle of July, is used for the construction of the curve.

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SOME PRACTICAL ASPECTS OF THE THEORY OF THE UNIFILAR HORIZONTAL-INTENSITY VARIOMETER

By S. E. Forbush

Abstract—The condition for stable equilibrium of a horizontal-intensity variometer, without control-magnets, is derived from the potential energy of the system. It is then shown that for quite sensitive variometers the equilibrium may, for a properly adjusted instrument, become unstable for subnormal values of horizontal intensity which occur during magnetic storms. The effect of temperature-compensation magnets on stability is treated. The scale-value equation is developed and it is shown that the factor which represents the change of scale-value with ordinate may be obtained directly from the value of the horizontal intensity at the instrument, and the optical lever. Tables indicate for three different instruments at widely different locations the agreement between the values calculated in this way and those obtained from the usual adjustment of observed scale-values. Finally, the effects of a control-magnet upon the conditions for stable equilibrium and upon the scale-value equation are investigated. The possibility of using a control-magnet to decrease temporarily the sensitivity of the instrument during severe magnetic disturbances is suggested. Some discrepancies between the scale-value equations derived in this note and those obtained by George Hartnell in his treatise on "Horizontal-intensity variometers" are indicated and explained.

Introduction— The purpose of this note is to derive the scale-value equation of the unifilar horizontal-intensity variometer, in terms of instrumental constants, in such wise that it can readily be compared with the results of observation, and to investigate the effect of a control-magnet upon the scale-value equation and upon the stability.

Insofar as the conditions for stable equilibrium are concerned, the results are found to agree with those obtained in a different manner by

Fig 1

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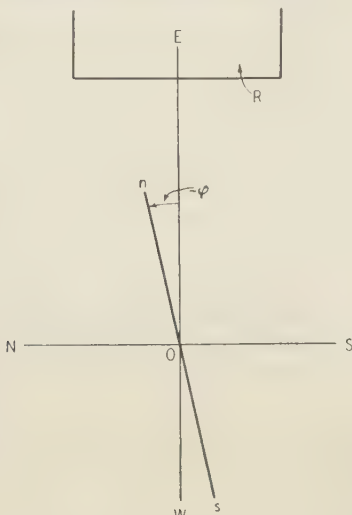
George Hartnell[1] in a comprehensive treatment on horizontal-intensity variometers. On the other hand, neither the scale-value equation of the instrument, without control-magnets, nor the effect of a control-magnet upon the factor giving the change of scale-value with ordinate, is found to be strictly in accord with the results given by Hartnell. The reason for these differences will be indicated at the conclusion of the note.

The equilibrium-equation and stability· –In Figure 1, n and s are the north-seeking and south-seeking ends of the magnet, suspended horizontally by a single vertical fiber at O; NS and EW are the magnetic meridian and magnetic prime-vertical, respectively; R is the recording-drum; ϕ is the angle, considered positive in the clockwise sense, between the prime vertical and the magnetic axis of the magnet; τ is the angular torsion in radians which must be introduced into the fiber (by turning the torsion-head) in order to make $\phi = 0$; $(\tau - \phi)$ is the angular torsion in the fiber for any value of ϕ; h is the torsion-factor of the fiber; M is the magnetic moment of the suspended magnet; and H is the magnitude of the horizontal component of the Earth's field at O. It is evident from Figure 1 that in the absence of a control-magnet the forces acting on the suspended magnet may be reduced to two couples, one mechanical and one magnetic. These are $h (\tau - \phi)$ and $- MH \cos \phi$, respectively, the negative sign of the latter being used to indicate that it acts in a counterclockwise direction, ϕ being considered positive in the clockwise sense.

Since the system is a conservative one, the forces are derivable from a potential, V say. Evidently we must have except for an additive constant

(1) $$V = MH \sin \phi + (h/2) (\tau - \phi)^2$$

so that

(2) $$-(\mathrm{d}V/\mathrm{d}\phi) = - MH \cos \phi + h (\tau - \phi)$$

For stable equilibrium, V must be a minimum, which requires that $\mathrm{d}V/\mathrm{d}\phi = 0$ and that $\mathrm{d}^2V/\mathrm{d}\phi^2 > 0$. The first condition is satisfied if

(3) $$- MH \cos \phi + h (\tau - \phi) = 0$$

which is the equilibrium-equation. The second condition is satisfied if

(4) $$- MH \sin \phi + h > 0$$

which, by substitution of h from (3), can be reduced to

(5) $\qquad\qquad \cot \phi > (\tau - \phi) \qquad$ for stable equilibrium

or to

(6) $\qquad\qquad \cot \phi < (\tau - \phi) \qquad$ for unstable equilibrium

As an illustration, consider the stability of a variometer set-up, at a distance of 115 cm from the recording-drum, at a place where H is normally $30{,}000\gamma$, so that $\phi = 0$ when $H = 30{,}000\gamma$ ($1\gamma = 0.00001$ c.g.s. unit). Further let a fiber be used such that $\tau = 7.5$ radians. As will be shown later, the scale-value of this instrument, for $\phi = 0$, will be about $1.7\gamma/\mathrm{mm}$. From (5) and (6) it is evident that in this case the equilibrium just becomes unstable for some critical value of $\phi = \phi_c$, such that

(7) $$\cot \phi_c = 7.5 - \phi_c$$

that is, if

[1]Horizontal-intensity variometers. U. S. Dept. Comm., Coast Geod. Surv., Spec. Pub. No. 89 (1922).

(8) $\phi = +7°.7$

Since the critical value of ϕ is positive, it is evident from Figure 1 that
the magnet will reach this position for some value of H less than $30,000\gamma$.
The corresponding critical value of H, say H_c, is found by solving equa-
tion (3) for H, so that

(9) $H = h\ (\tau - \phi)/M \cos \phi$

Now if, as postulated above, $\phi = 0$ when $H = 30,000$, it is evident from
(9) that

(10) $h/M = 30,000/\tau$

Substituting for h/M in (9) the value given by (10) and further putting
$\tau = 7.5$ radians and $\phi \doteq +7°.7$, we have $H_c \doteq 29,730\gamma$. That is to say,
a decrease of approximately 270γ in horizontal intensity would allow
the magnet to reach the position of unstable equilibrium. For values
of H less than about $29,730\gamma$ (that is, for values of ϕ greater than about
$+7°.7$), the mechanical couple on the magnet is greater than the magnetic
couple. The result is that the torsion in the fiber "takes charge" so to
speak, the fiber "unwinds", and the system eventually comes to rest at
a new position which is of little practical interest.

For the same variometer, approximate values of H_c for various values
of τ (that is, for other fibers) are given in Table 1. The approximate
values of ϵ_0 (the scale-value for $\phi = 0$), of ϕ_c, and of $\triangle H = 30,000\gamma - H_c$

TABLE 1—*Values where $H = 30,000\gamma$*

τ	ϵ_0	ϕ_c	H_c	ΔH
radians	γ/mm	°	γ	γ
7.5	1.7	+ 7.7	29730	270
7	1.8	8.3	29700	300
6	2.1	9.7	29590	410
5	2.6	11.8	29400	600
4	3.2	15.0	29020	980
3	4.2	20.8	28220	1780
2	6.4	36.1	25440	4560
$\pi/2$	8.1	90.0	0	30000

are also given. Table 1 shows, for various values of τ (that is, for various
fibers), the values of ϕ_c, together with the corresponding values of
H_c and $\triangle H$, at which the equilibrium becomes unstable. The ap-
proximate scale-value, ϵ_0, for $\phi = 0$ is given in each case. This instru-
ment is supposed adjusted for a normal value of $H = 30,000\gamma$ (that is,
it is set so $\phi = 0$ when $H = 30,000\gamma$). $\triangle H$ is simply the approximate
decrease, in gammas, in the horizontal intensity which permits the magnet
to attain a position of unstable equilibrium. It should be noted that for
values of $\tau \leq \pi/2$, H can decrease to zero without the equilibrium
becoming unstable.

If the variometer were, as we have supposed, set up with $\phi = 0$ when
$H = 30,000\gamma$, then it is evident that for the case of the smaller scale-
values, the decrease in H which could arise from even a moderate mag-
netic storm would allow the magnet to reach the position of instability
and "unwind." However, in any case, the recording-spot would probably
go off the record before the position of instability were reached. Both

facts emphasize the conclusion that the useful range of the above vari-
ometer is exceedingly limited if the scale-value (for $\phi = 0$) is even as small
as $2\gamma/mm$.

Table 2 gives the approximate values of ϵ_0, ϕ_c, H_c, and $\triangle H$, which
obtain for the same values of τ used in Table 1, if the instrument is set
up as before but at a place where H is normally $15,000\gamma$ instead of $30,000\gamma$.
That is, the instrument is now adjusted so that $\phi = 0$ when $H = 15,000\gamma$.
From Table 2 it is evident that, for the same ϵ_0, H must, in this case,
decrease more than in the case of Table 1 before the magnet reaches a
position of unstable equilibrium. As in Table 1, if $\tau \leq \pi/2$, then H
can decrease to zero without the equilibrium becoming unstable.

TABLE 2—*Values where $H = 15,000\gamma$*

τ	ϵ_0	ϕ_c	H_c	$\triangle H$
radians	γ/mm	°	γ	γ
7.5	0.8	+ 7.7	14865	135
7	0.9	8.3	14850	150
6	1.0	9.7	14795	205
5	1.3	11.8	14700	300
4	1.6	15.0	14510	490
3	2.1	20.8	14110	890
2	3.2	36.1	12720	2280
$\pi/2$	4.0	90.0	0	15000

In order to consider the effect on the critical values of ϕ of mounting
magnets in such a way as to compensate the variometer for temperature-
changes, let the variometer be set up as in the first case where $H = 30,000\gamma$.
The compensating-magnets must necessarily be mounted so that the
value of H at the variometer is reduced. If the temperature-coefficient
of the variometer-magnet is identical with that of the compensating-
magnets, a condition probably not often realized in practice, then
Hartnell[2] has shown that the horizontal intensity at the center of the
variometer must be reduced to half its value in order to effect compen-
sation. Thus, if $H = 30,000\gamma$, it is assumed to be reduced to $15,000\gamma$
for compensation. If now such fibers are used that the values of τ
indicated in Table 2 obtain, then the values of ϵ_0. ϕ_c, H_c, and $\triangle H$ in-
dicated in Table 2 will apply.

It must be emphasized that even if a fiber is chosen such that the
critical values of ϕ are not likely to occur, this by no means insures satis-
factory adjustment of the variometer. For, if the variometer is to
record variations in H and only variations in H, this demands that the
angle ϕ be at all times small – much less than the least of the critical
values of ϕ_c shown in the tables.

In the above discussion we have assumed that the value of H was
known for $\phi = 0$. In practice it is not possible to know accurately either
the value of H for $\phi = 0$ or the value of ϕ for a particular value of H
unless special measurements are made. The information could however
be obtained from the usual magnetograph-records if the following facts
were also known: (1) The azimuth of a line through the point of sus-
pension of the variometer-magnet and piercing the photographic record
at a known point; (2) the angle between (1) and a line through the point

²*Loc. cit.*, pp. 42-43.

of suspension of the variometer-magnet and the slit of the light-source;
(3) the angle, in the horizontal plane, between the magnetic axis of the
magnet and the normal to the plane of the mirror which is attached.
Besides enabling one to determine whether the variometer is in good
adjustment (that is, whether ϕ is not large) the above information can be
of considerable use in connection with scale-values of the instrument,
as will be seen later.

The scale-value equation—In γ/radian the scale-value for any par-
ticular value of ϕ, say ϕ_p, is simply the value of $dH/d\phi$ for $\phi = \phi_p$, with
H in γ. From equation (3)

(11) $$H = (h/M) \ (\tau - \phi) \ \sec \phi$$

Hence

(12) $$dH/d\phi = (h/M) \ [-\sec \phi + (\tau - \phi) \ \sec \phi \ \tan \phi]$$

The right-hand member of (12) can be expanded in a power series in
ϕ with the result

(13) $$dH/d\phi \doteq (h/M) \ [-1 + \tau\phi - 3 \ \phi^2/2]$$

If a critical value of ϕ and the corresponding τ from Table 1 or 2 are
substituted in (12), the result is that $dH/d\phi \doteq 0$, the approximation
being necessary only because the critical values of ϕ in the tables are
approximate. This shows, as would be expected, that at the limit of
stability the scale-value becomes zero or that the sensitivity becomes
infinite.

For practical purposes, since (13) is not convenient, it is better to
have the scale-value in γ/mm, which is denoted by ϵ_n and is simply
dH/dn, n being in millimeters on the magnetogram. For convenience,
it is assumed that the recording-spot of the variometer falls on the
base-line of the magnetogram when $\phi = 0$. n is the ordinate in milli-
meters from the base-line to any point on the H-variometer curve. Now

(14) $$\epsilon_n = dH/dn = (dH/d\phi) \ (d\phi/dn)$$

Since recording is accomplished by a beam of light reflected from a
mirror at O, n if considered positive in the direction in which the spot
on the magnetogram moves when H increases, is given in terms of ϕ,
and L the optical distance from the mirror at O to the base-line on the
magnetogram by

(15) $$-n \doteq 2\phi L$$

in which $\tan 2\phi$ has been replaced by its approximate[3] value of 2ϕ.
Furthermore, from (15)

(16) $$d\phi/dn \doteq -(1/2L)$$

Thus from equations (13), (14), (15), and (16) is obtained

(17) $$\epsilon_n = (h/M) \ \{1/2L + \tau \ n/(2L)^2 + (3/2) \ [n^2/(2L)^3]\}$$

In practice n and $2L$ are usually such that the last term in (17) can be
neglected. This is further shown by the fact that scale-values observed
at different ordinates, n, can usually be represented within the accuracy
of the observations by the form

[3]If the exact relation is used, the conclusions which follow remain unchanged.

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(18) $\epsilon_n \doteq A + B\, n$

in which A and B are constants and as before ϵ_n is the scale-value in γ/mm at the ordinate n. Comparing the coefficients of n in (17) and (18), it is evident that

(19) $A = (h/M)\ (1/2L)$

(20) $B = (h/M)\ \tau\ [1/(2L)^2]$

If now in equation (3) we know the value of H, say H_0, for which $\phi = 0$, we obtain

(21) $H_0 = h\ \tau/M$

whence (19) and (20) become, respectively

(22) $A = (H_0/\tau)\ (1/2L)$

(23) $B = H_0/(2L)^2$

Equation (23) is an important one, for by means of it B can easily be computed with greater precision than it is possible to obtain by the longer process of adjusting the observed scale-values to equation (18). Furthermore, a close approximation to B is obtained provided ϕ is small compared to τ, even though an approximate value of H is used in (23). The agreement between the values of B predicted by (23) and those obtained by the adjustment of observed scale-values to the form (18) is shown at three stations in Table 3.

TABLE 3—*Comparison of observed and calculated values of B at three stations for periods when the variometers were operating without temperature-compensation or control-magnets*

Station	Approx. H	L	Calculated B	Observed B
	γ	mm	γ/mm^2	γ/mm^2
Huancayo	29600	1150	.0056	.0057
Watheroo	24700	1130	.0047	.0050
Cheltenham	19120	1150	.0036	.0035

Since the effect of compensating the variometer for temperature will be to reduce H at the variometer, it is evident from (23) that this also reduces B in the same ratio. By knowing the angle through which the torsion-head of the variometer has to be turned in order to bring the suspended magnet back into the position $\phi \doteq 0$, after the compensating-magnets have been attached, the new value of H at the center of the instrument can be estimated *provided* the value of τ, before or after compensation, is known. If the scale-value for $\phi = 0$ is known from observation, then from (22) a value of τ can be computed. If the special measurements, which were described earlier, for determining the angle ϕ have been made, then the scale-value for $\phi = 0$ is known and the new B can be computed.

The fact that equations (19) and (20) do not contain ϕ has a useful application. Suppose that for some reason it is desired to shift the position of the H-curve on the magnetogram by turning the torsion-head of the H-variometer, that is, by slightly altering ϕ. Let this be done preferably on a day magnetically quiet and at a time of day when

H is changing very little, and furthermore let the shift be accomplished quickly, assuring that the value of H will be very nearly the same just after the shift as it was just before. If the ordinate before the shift were n_1 and that after the shift were n_2, then the scale-values, since A and B remain unchanged, for these two points are from (18), respectively

$$(24) \qquad \epsilon_{n_1} \doteq A + B \, n_1$$

$$(25) \qquad \epsilon_{n_2} \doteq A + B \, n_2$$

in which the degree of approximation is that incurred in (17) by neglecting powers of n higher than the first. To this extent the change in scale-value is the usual change due to a change in the ordinate. Furthermore, if $B L_1$ be the base-line value before the shift and $B L_2$ that after the shift, then since the value of H is supposed the same before and after, it is evident that

$$(26) \qquad BL_1 + [A + (B/2)\, n_1]\, n_1 = BL_2 + [A + (B/2)\, n_2]\, n_2$$

hence

$$(27) \qquad BL_2 = BL_1 + (n_1 - n_2)\, [A + (B/2)\, (n_1 + n_2)\,]$$

Thus from (27) and under the conditions postulated, the new base-line value can be readily obtained from the *old* one with an accuracy not likely to be attained from less than half a dozen absolute observations.

Effect of a control-magnet on stability and scale-values—Consider the case of a control-magnet mounted east of O (Fig. 1), with its axis coinciding with the line EW, and with its north-seeking end east. Analogous to (1) we will have in this case, except for a constant,

$$(28) \qquad V = M\, H \sin \phi + (h/2)\, (\tau - \phi)^2 - M\, F \cos \phi$$

in which F is the field in gammas at O due to the control-magnet. From (28)

$$(29) \qquad -dV/d\phi = -M\, H \cos \phi + h\, (\tau - \phi) - M\, F \sin \phi$$

$$(30) \qquad d^2V/d\phi^2 = -M\, H \sin \phi + h + M\, F \cos \phi$$

From (29) the equilibrium-equation is

$$(31) \qquad -M\, H \cos \phi + h\, (\tau - \phi) - M\, F \sin \phi = 0$$

The equilibrium is stable if $(d^2V/d\phi^2) > 0$, that is, if

$$(32) \qquad -M\, H \sin \phi + h + M\, F \cos \phi > 0$$

Substituting h from (31) in (32) and putting $F = K\, H$, (32) can be reduced to

$$(33) \qquad \cot (\phi - \alpha) > (\tau - \phi)$$

in which $\tan \alpha = K$, which reduces to (5) in the absence of a control-magnet, since $K = 0$. Comparing (33) and (5), it can be seen that the effect of mounting a control-magnet in the manner described is to increase the critical angle ϕ_c at which the system becomes unstable. If now the control-magnet is mounted in the same position as before but with its north-seeking end west instead of east, the critical angle at which the system becomes unstable is decreased. In this case, equation (33) still applies but α is now defined by $\tan \alpha = -K$.

To determine the effect of the control-magnet on the scale-value, (31) is solved for H with the result

$$(34) \qquad H = (h/M) \ (\tau - \phi) \ \sec \phi - F \tan \phi$$

so that

$$(35) \quad dH/d\phi = (h/M) \ [-\sec \phi + (\tau - \phi) \ \sec \phi \ \tan \phi] - F \ \sec^2 \phi$$

Except for the last term, (35) is identical with (12), so that the expansion of (35) in a power series in ϕ is readily obtained by adding to (13) the expansion for $-F \sec^2 \phi$, with the result

$$(36) \qquad dH/d\phi \doteq (h/M) \ (-1 + \tau\phi - 3 \ \phi^2/2) - F \ (1 + \phi^2)$$

Using the relations (13), (14), and (15), the scale-value ϵ'_n in γ/mm becomes

$$(37) \qquad \epsilon'_n \doteq (h/M) \ \Big\{ 1/2 \ L + \tau n/(2L)^2 + (3/2) \ [n^2/(2L)^3] \Big\} + F \ [1/2L + n^2/(2L)^3]$$

or

$$(38) \qquad \epsilon'_n \doteq (1/2L) \ [(h/M) + F \ ] + h\tau n/M \ (2L)^2 + [1/(2L)^3] \ (3h/2M + F) \ n^2$$

For $\phi = 0$ in (34) we have $H_0 = h\tau/M$, as before, so that using (19) and (20), (38) becomes

$$(39) \cdot \qquad \epsilon'_n \doteq (A + F/2L) + B \ n$$

in which the last term in (38) has been neglected. From (39) it is evident that the effect of the control-magnet mounted east of O (see Fig. 1) and with its north end east is to increase the value of A, that is, the scale-value in γ/mm (for $\phi = 0$) is increased by $F/2L$ (F in γ, L in mm), and further that the value B remains unchanged. If the control-magnet is east of O and with north end west, then A is decreased by $F/2L$.

It must be emphasized in this discussion of the effect of a control-magnet that it has been assumed that the field, due to the control-magnet, in the region about the suspended magnet is uniform and parallel to EW.

It frequently happens that at observatories equipped only with comparatively sensitive instruments some of the records are lost during magnetic storms. It seems, however, from the above discussion, that in order to keep the recording-spot of the H-variometer on the record during a magnetic storm a control-magnet might temporarily be used to increase the scale-value. This however would necessitate a determination of the scale-value and base-line with the control-magnet in place. Furthermore, any effect of the control-magnet upon the declination variometer and the vertical-intensity variometer would have to be determined and corrected.

In conclusion, the writer wishes to acknowledge that some of the material developed in this note may be found in the publication "Horizontal-intensity variometers" by George Hartnell, to which reference has already been made. It is hoped that any duplication may serve to emphasize the usefulness of facts which he has already pointed out.

Attention must, however, be called to two discrepancies between the results obtained by Hartnell and those given here. The first of these concerns equation (17), which for the purpose of clearly indicating the discrepancy will be transformed by means of the relations (21) into

(40) $\qquad \epsilon_n \doteq (H_0/\tau)\ \epsilon + H_0 \epsilon^2 n + (3/2)\ (H_0/\tau)\ \epsilon^3\ n^2$

in which $1/2\ L$ has been replaced by ϵ to conform to the notation used by Hartnell. Equation (40) may now be compared with Hartnell's equation (66) on page 23 of his work above referred to. The essential difference lies in the fact that the coefficient of n in his equation depends on the value of τ, whereas the coefficient of n in equation (40) is independent of τ. This difference arises from the fact that Hartnell in developing his equation (66) has assumed the value of H to be constant *before* expanding in a power series in ϕ the expression for the scale-value, whereas in this note no such assumption has been made until *after* the series expansion has been obtained.

[*Note*—The treatment of τ above as a constant is justified since τ is simply the angular torsion which must be introduced into the fiber to bring the suspended magnet into the magnetic prime-vertical. At the moment this is done H has a particular value and τ depends on H in the sense that it would be different were H different at the moment the suspended magnet is put in the prime-vertical. In other words, the torsion in the fiber is τ for only that particular value of H which prevails when the magnet is put in the prime-vertical, *but* now if H changes the torsion in the fiber is of course no longer τ but $(\tau - \phi)$ and so the torsion in the fiber for any value of H is completely defined in terms of a constant τ and a variable ϕ. This justifies the expansion in terms of ϕ.]

The same process accounts for the second discrepancy which arises in connection with equation (39) of this note, which indicates that the factor B in equation (18) is not altered by mounting a control-magnet east or west (magnetic) of the suspended magnet, if the axis of the control-magnet is in the magnetic prime-vertical, whereas Hartnell (see bottom of page 29 of his work) concludes that a control-magnet mounted as described does alter the factor designated as B in this paper.

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REVIEWS AND ABSTRACTS

Hess, V. F.: *Die Ionisierungsbilanz der Atmosphäre.* Sonderdruck aus Ergebnisse der Kosmischen Physik, Bd. 2 (Beitr. Geophysik, Supplementband 2), 1933 (95-152). [Leipzig, Akademische Verlagsgesellschaft.]

This report is naturally divided under three main heads: (a) Ionization-processes in the atmosphere; (b) ion-destroying processes in the atmosphere; and (c) the ion-balance in the atmosphere. The above processes apply of course solely to the small or light ions and not to ions in general. The author discusses the different processes by which ions are produced in the atmosphere. Among the ionizers in the lower levels of the atmosphere, the radiations of radio-active origin are of prime importance. The author has gone into considerable detail to show the relative importance of the various radioactive materials found in the Earth's crust in contributing directly and indirectly to the number of ions in the different layers of the atmosphere. The different radiations, a, β, and γ are also compared as to their contributions to the production of ions, near the Earth's surface and at some distance above the surface. The part played by cosmic radiation is discussed and a table and graph are shown of the variation in ionization with height and also that actually observed. The combination of small ions with charged and uncharged condensation-nuclei is regarded as one of the most important ion-destroying processes, in those localities where the nuclei are numerous. The Schweidler linear recombination-law and also the Nolan quadratic recombination-law are discussed in considerable detail. The ion-content of the stratosphere is also discussed in a very general way, and the intensity of ionization (due to cosmic radiation) and ion-numbers at various heights from 11 to 40 km are given in the form of a table. The author gives a very extensive bibliography, at the end of the article, which should prove of considerable value to those seeking more detailed information regarding any particular investigation. The list also indicates how thoroughly the subject has been gone into by the author of this article. The present work will be welcomed by the workers in this field, since it takes into account the most important advances made since 1927 when much of the ground work was covered by the author in his book on "The electrical conductivity of the atmosphere and its causes." The present treatise is well and carefully prepared, and is all the more valuable coming from the pen of one who has done important investigational work in this field.   G. R. WAIT

ON THE POSSIBILITIES OF A TIDAL EFFECT IN THE KEN-NELLY-HEAVISIDE LAYER AS EVIDENCED BY AN AP-PARENT CORRELATION OF THE INTENSITY OF RADIO RECEPTION WITH POSITIONS OF THE MOON

By Harlan T. Stetson and Josef J. Johnson

Previous papers[1] have pointed out the probable existence of a correlation between the intensity of radio reception and the Moon's position in the observer's sky at the time the intensity-measurements are made. Corroborating evidence has come from subsequent investigations by Pickard[2] and by Kenrick and Pickard,[3] as to the reality of the lunar effect. The variation in intensity considered implies a rise and fall in the Kennelly-Heaviside Layer, or an equivalent change in the electron-density of the ionosphere, which assumes the appearance of an electronic tide. It was pointed out in the first paper mentioned that such might be caused either by the Moon's gravitational effect on the upper atmospheric layers or by some unknown effect of the Moon acting as an ionizing agent, such, for example, as would be the case were the Moon to possess an appreciable electrostatic charge.

With the accumulation of quantitative radio data at the Perkins Observatory for the primary purpose of furthering the studies of correlation between solar activity and radio reception,[4] it has been possible to investigate more extensively the lunitidal effect on the basis of a larger amount of observational data than appeared in the preliminary paper. In discussing the results it appears profitable to summarize certain characteristics of the ionosphere as a preliminary step to the approach of a discussion of the observations and inferences which may be drawn therefrom. The problem of transmission of radio waves is highly complicated and no entirely satisfactory theory of propagation has yet been evolved. Under certain ideal conditions, the principal assumption being that the ground is an infinite, perfectly-conducting plane, it has been shown that the intensity of the electrical field[5] at a distance r (in kilometers) from the sending station is given by the expression

$$E = 1.2 \times 10^{-3} \pi \ (H/\lambda) \ (1/r) \ I_s$$

where H = height of (vertical) antenna, λ = wave-length, and I_s = effective current at the base of the antenna. This electrostatic field, perpendicular to the conducting plane, is accompanied by a discharge

[1] H. T. Stetson, On the correlation of radio reception with the Moon's position, Perkins Obs. Sci. Papers No. 8, Terr. Mag., **36**, 1-5 (1931); Investigations at the Perkins Observatory of changes in the Kennelly-Heaviside Layer as a function of lunar altitudes, Trans. Amer. Geophys. Union, 12th Annual Meeting, 124 (1931).

[2] G. W. Pickard, Notes on correlation-investigations between Kennelly-Heaviside Layer and lunar altitudes, Trans. Amer. Geophys. Union, 12th Annual Meeting, 125-126 (1931).

[3] G. W. Kenrick and G. W. Pickard, Some common periodicities in radio transmission phenomena, Trans. Amer. Geophys. Union, 13th Annual Meeting, 172-179 (1932).

[4] H. T. Stetson, Influence of sunspots on radio reception, Perkins Obs. Sci. Papers No. 3, J. Frank. Inst., **210**, 403-419 (1930); Progress in studies of cosmic correlations with radio reception at the Perkins Observatory, Perkins Obs. Sci. Papers No. 13, Trans. Amer. Geophys. Union, 13th Annual Meeting, 180-181 (1932); Sunspots and radio reception, Perkins Obs. Sci. Papers No. 14, Smithsonian Inst. Rep. for 1931, 215-228; Some results of further studies in the correlation of cosmic phenomena with radio intensities as measured at the Perkins Observatory, Perkins Obs. Sci. Papers No. 17, Trans. Amer. Geophys. Union, 14th Annual Meeting, 127-129 (1933).

[5] P. O. Pedersen, Propagation of radio waves along the surface of the Earth and in the atmosphere, p. 10 (1927).

of electromagnetic energy, the vibration being in the direction of the radius-vector and the intensity being in accordance with a similar equation, except that it is also proportional to $\sin^2 \phi$, where ϕ is the angle between the radius-vector and the axis of the antenna. Due to two causes, the Earth's surface having a finite curvature and not being a perfect conductor, both the field-intensity and the electromagnetic energy are somewhat less than those derived for the ideal case. Even so we should expect, if there were no other factors, that these quantities would be constant for transmission at a given power output over a fixed path, whereas actual measurements show great variations. Again, while it was at first assumed that radio waves could follow along the curved surface of the Earth as alternating current follows along a conductor, calculations of intensities and field-strengths showed the idea to be untenable, and made it increasingly difficult to account for radio transmission over longer distances than would permit a straight-line path from antenna to antenna. Considerations such as these led early to the now universally accepted hypothesis of a spherical conducting-layer surrounding the Earth.

Ionization in the upper atmosphere seemed the most feasible mechanism for providing the required conducting-layer, and the hypothesis has been abundantly verified by many different lines of attack. Among the suggested primary causes of the ionization of this layer have been mentioned the ultraviolet radiation from the Sun, the highly penetrating cosmic-radiation, and bombardment by corpuscles, by β-particles or electrons.

Whatever the primary cause, the amount of ionization at any given height in the atmosphere is governed by the composition and physical conditions there prevailing. Ionization and the resulting conductivity depend, among other things, upon the mean free-path of molecules and ions. Under standard conditions of temperature and pressure ($0°C$ and 760 mm), the average value of the mean free-path amounts to approximately 6×10^{-6} cm.[6] Since this quantity varies inversely as the pressure, it attains lengths of many meters, and possibly even kilometers, at extreme heights. The mean velocities of atmospheric ions and electrons at $0°C$ may be taken as 4.5×10^4 cm, sec and 9.15×10^6 cm/sec, respectively.

These long free-paths, it should be noted, preclude the possibility of an appreciable electric field in the ionized portions of the stratosphere; for could a field be created it would immediately become compensated by displacements of charges. Large fields are possible in the lower atmosphere, however, where the free-paths are short. Measurements show that at sea-level there is a normal gradient of about one volt per centimeter downward; that is, corresponding to a negative charge on the Earth. This disminishes to 0.25 v/cm at a height of 1.5 km, and to 0.04 v/cm at 9 km, approaching zero at higher altitudes.[7] Normally in the lower atmosphere the potential thus increases with increasing height, but occasional electrical storms give rise to discontinuity surfaces and enormous gradients. Fields up to 1500 v cm are believed to exist immediately below thunder-clouds. Surfaces of discontinuity may occur in clear air, but are more commonly found at the transition between clouds and clear air.

[6] P. O. Pedersen, *ibid.*, p. 42.
[7] P. O. Pedersen, *ibid.*, p. 45.

Direct measurements of atmospheric ionization have been made, up to heights of 15.5 km, by measuring the conductivity of air exposed to the action of a constant electric field. There are on the average about 500 ions per cubic centimeter at the surface of the Earth. The number decreases to a minimum at a height between one and two kilometers, then increases again. Aside from observational methods, ionization at greater heights can be determined from analytical considerations involving probability of recombination of ions, the determination of the number of free electrons, and the rate of absorption of external radiation. Furthermore, the interdependence of all these factors with conductivity and radio propagation over a large range of wave-lengths, has made possible quite accurate determinations of the composition and pressure for heights of from 80 to 160 km, the region in which we are particularly interested, determinations which check with data from observations of meteors, aurora borealis, and terrestrial magnetism.

According to Pedersen,[8] most calculated values of atmospheric ionization have been too low. They have been based upon an assumed solar constant of 1.35×10^6 ergs/cm² per second, a solar temperature of 6000° K, and black-body distribution of radiation. The first two assumptions are justifiable, but the last may lead to serious error. Pedersen proposes the theory that electrons, ions, and α-particles expelled from the Sun ionize the upper part of the solar chromosphere, which in turn gives forth a powerful radiation in the extreme ultraviolet, much more than would be expected from a black-body distribution. The hypothesis is confirmed by the circumstance that the conductivity of the air is about 50 per cent greater at sunspot-maximum than at sunspot-minimum.

Stellar radiation may have an appreciable effect in producing atmospheric ionization. The Sun is 10^8 times as bright as all the stars combined, but some stars are much hotter and therefore relatively much stronger in the ultraviolet. With certain plausible assumptions as to stellar temperatures, the total ultraviolet radiation from the stars comes out about 10^{-3} times that of the Sun. It may be even more effective than this figure would indicate, because of greater penetrating power. The recent results of Jansky[9] in observing a persistent "hiss" of apparently extra-terrestrial origin may be increased evidence for seriously considering stellar sources of ionization.

Laboratory experiments show that nitrogen and oxygen are ionized particularly by ultraviolet light of wave-lengths between λ1800 and λ1200 Å. The height above the surface of the Earth of the Kennelly-Heaviside Layer will then be determined by the depth to which these rays can penetrate. As all heights above this critical level must necessarily be traversed by these rays, we should expect the ionized state to continue without interruption from this level up to the extreme upper limit of the atmosphere. Pedersen supports this view, and therefore objects to the term "layer" as being inappropriate when applied to a highly ionized *region* extending from about 80 km to several hundred kilometers above the Earth's surface.[10]

There is abundant evidence, however, of the existence of not only

[8]P. O. Pedersen, *ibid.*, p. 74.
[9]K. G. Jansky, Electrical disturbances of extra-terrestrial origin, Proc. Inst. Radio Eng., **21**, 1387-1398 (1933).
[10]P. O. Pedersen, The propagation of radio waves, pp. 70 and 79.

B

one but several real "layers." The height of the lower stratum, as in-
dicated by the Bureau of Standards[11] tests, varies between 100 and 150
km, that of the upper between 200 and 350 km. Both strata are near
their upper limits at night and are depressed to varying degrees during
the daylight hours. The conductivity of the ionized layer is due to both
ions and free electrons, the latter being the more important. For slowly
varying currents, the conductivity due to electrons, which in any case
is many times that due to ions, is, at a height of 100 km, more than a
thousand times smaller because of the Earth's magnetic field than it
would be without the field, while at 150 km the difference is 10^5 times[12].
The effect decreases with increasing frequency and is therefore very
much less for the range of frequencies used in radio work, but is still
sufficient to affect radio reception severely during a "magnetic storm"
and to affect it measurably during minor magnetic fluctuations.

Attempts have been made at Greenwich[13] and elsewhere to measure
the lunar tide in the atmosphere by means of the barometer, and only
through the analysis of a long series of observations have definite re-
sults been obtained, the measurable average lunar pressure-wave show-
ing the extreme variation of 0.02 mm.[14] It is difficult to see how so
small a percentage-range can of itself produce a sufficient variation in
the height of the ionized layer to effect appreciable variations in the
transmission of radio waves on this account. However, barometric
indications could not be expected to measure a tidal effect due to a
change in ionization, or to exhibit differential changes in vertical com-
pression or expansion of the various atmospheric strata, such as might
be caused by resonance, unless the total mass-content over a given
area were thereby modified.

Many measurements have been made in Norway[15] of the heights
of the bases of aurorae, the usual range being from 90 to 120 km above
the Earth's surface. From the analysis of the results of nearly two
thousand observations Egedal[16] comments that during ebb-tide in the
atmosphere the maximum of 100 km was predominant, while during
flood-tide the maximum at 106 km was predominant. Investigations
of the frequency-curve indicate that the maxima may be considered as
displacements of one and the same maximum. From this he concludes
that as regards the locality the mass of air situated above 100 km at
ebb-tide is the same as the mass of air situated above 106 km at flood-
tide. These measurements, made in latitude 70° north, would, according
to Egedal, surely have larger values in lower latitudes, perhaps amount-
ing to a variation of as much as 25 per cent in the conducting layer.
This apparently hazardous extrapolation may appear more plausible
in the light of certain magnetic observations in the tropics. Investiga-
tions at Batavia have revealed a tidal variation amounting to 21 per
cent of the magnetic declination. As one may assume that the con-
ductivity of the ionized layer varies approximately with atmospheric

[11] J. H. Dellinger and W. N. Kerr, and K. A. Norton, Investigations of Kennelly-Heaviside Layer for frequencies ... Bur. Stan. J. Res. 7, 1085-1104 (1931).

[12] P. O. Pedersen, The propagation of radio waves, p. 114.

[13] R. Gregory, Weather-recurrences and weather-cycles, Monthly Weath. Rev., 58, 483-490 (1930); see also Science News Letter, 21, 206 (1932). J. Bartels, research associate of the Carnegie Institution of Washington, finds evidence of a barometric lunar tide ... a lunar wave which is exactly the sort of tide that would be produced by a gravitational action of the Moon.

[14] J. Bartels, Tides in the atmosphere, Sci. Mon., 35, 110-130 (1932); also Carnegie Inst. Sup. Pub. No. 5, 48-68 (1932).

[15] C. Störmer, Twenty-five years' work on the Polar Aurora, Terr. Mag., 35, 193-208 (1930).

[16] J. Egedal, Variation of conductivity of the upper atmosphere, Nature, 123, 642-643 (1929).

density and mean free-path, and that such properties will vary directly with an atmospheric tide, we may regard these magnetic observations as furnishing additional evidence to the tidal hypothesis. Whatever the factors may be which contribute to a tidal effect in the ionized layer, Egedal concurs in the belief that records of the intensity of radio reception probably furnish the best all-round means at our disposal for further investigation. Whether the effect of the Moon in producing tides in the Kennelly-Heaviside Layer is gravitational or electrostatic, the variation of the force on either assumption should follow the recognized laws of the two-body problem. In the present investigation in which the solar partial tide has presumably been eliminated from the observational data, as will be later explained, we can be concerned for the moment with only the principal lunar terms involved.

The rigorous expressions for the height of the lunar equilibrium-tide for a given time and place are long and complicated, but comparatively simple approximations may be written which account for about 98 per cent of the total effect and are sufficiently accurate to compare with the observational data where accidental errors will, in general, far exceed 2 per cent.

The equilibrium-height of the principal lunar tide is given by[17]

$$y = (K/d^3) \ (3 \cos^2 \theta - 1) \tag{1}$$

where $K = (1 \quad 2) \ [$ (mass of Moon) (radius of Earth)$^4]$ (mass of Earth, $d =$ distance between Moon and Earth, and $\theta =$ the angle at the center of the Earth between the Earth-Moon line and the direction of the observer, or of the point on the Earth's surface for which the tide is to be computed. Neglecting horizontal parallax, we may make approximation as follows: $\theta = $ Moon's zenith-distance or $\theta = (90° - h)$ where $h = $ Moon's altitude. An equation for the vertical component of the tide-producing force differs from (1) only in the value of K.

The "equilibrium"-tide is that theoretical tide which would result if the medium responded freely and immediately to the tidal force. The actual ocean-tide is modified by many factors. First of all there is in lower latitudes the inversion of phase, a phenomenon common to all oscillating systems when subjected to a forced vibration of greater frequency than the natural period. Frictional resistance to the motion of the tidal wave relative to the rotating Earth results in a further phase-displacement. The interference due to the land-masses of the Earth produces all sorts of irregularities which, together with the previously mentioned terms, comprise the "establishment of the port," the observed time-interval at any particular place between the meridian passage of the Moon and the next succeeding high-water.

Conditions in the atmosphere are quite different, however. We know from barometric measurements that there can be no appreciable shift of large quantities of air from one place to another, comparable for instance to the inrush of water over a continental shelf with a rising oceanic tide. Therefore an atmospheric tide must of necessity be mainly a matter of compression and expansion; of vertical displacement of the various strata with a minimum of horizontal motion. In such a case we should expect the frictional lag to be very small. Continents, even with high mountain ranges, could hardly be expected to have an important

[17]P. Schureman, *Manual of the harmonic analysis and prediction of tides*, Equation (44), p. 23.

effect upon atmospheric movements at heights of 50 km and over. For these reasons we feel justified in disregarding entirely those modifying factors which are so important in the case of oceanic tides, and in making use of the equilibrium-tide in our study of possible correlations.

The value of y, the height of the equilibrium-tide, may be computed for any time and place from equation (1). The factor K may well be left arbitrary in computing an atmospheric tide, for the amplitude probably varies with the height above the Earth's surface and can be only approximately estimated for any given height. The computation was carried out at the Perkins Observatory for two-hour intervals for the month of April 1930, the first month for which the radio data were available. It soon became evident, however, that an excessive amount of time and labor would be required in carrying on the computation to cover a period of several years. It is to be noted that there are two variables, θ and d, neither of which varies uniformly with time. Moreover, θ depends upon a number of elements, such as right-ascension, declination, sideral time, which must be found for each instant of time for which the value of y is required.

By harmonic analysis the actual observed tide at any place may be separated into a number of partial or constituent tides, the rise and fall of each tide being a simple harmonic function of time. Prediction then consists in reuniting the partial tides in accordance with the relations which will prevail at the time for which the predictions are to be made. Considered geometrically, it is as if the Sun and Moon were replaced, for tide-producing purposes, by a large number of small satellites, each revolving about the Earth in a circular orbit at a constant angular velocity and each generating its own component of the total tide. Over one hundred components are used by the United States Coast and Geodetic Survey in connection with their tide-predicting machine at Washington, but many of these are of very small amplitude. For this reason, and also because we are disregarding the solar components, which make up about one-third of the total, we are particularly interested in only a small number, of which the four most important are designated by the following notation:

Symbol	Description	Maximum equilibrium-value in feet
M_2	Principal lunar	0.79
N_2	Larger lunar elliptic	0.15
O_1	Principal lunar diurnal	0.33
K_1	Lunisolar diurnal (lunar portion only)	0.32

The fundamental formula for a component is,

$$V_1 = H \cos [at + (V_0 + u) - K] \tag{2}$$

where H = amplitude (semi-range) of a component, K = epoch-angle of a component, $(V + u)$ = theoretical phase of a component for any time t as derived from the equilibrium-theory, and a = "speed" of a component, that is, units of angle per unit of time.

H, K, and a are perhaps self-explanatory. V is composed of several elements, namely, the hour-angle of the mean Sun, the longitude of the mean Sun, the longitude of the mean Moon, the longitude of the Moon's

perigee, and numerical constants; it changes uniformly throughout 360° The quantity u is a function of the regression of the nodes of the Moon's orbit. It has a period of approximately nineteen years, and hence may be regarded as constant for small periods of time. Tables are given in Schureman's manual from which it is possible to obtain the values of H, K, (V_0+u), and a for any time and place. The value of each component may then be computed; the summation of the components gives the total tide. This method lends itself exceedingly well to mechanical treatment, as with the tide-predicting machine at Washington, where tides are forecast for many different stations for long periods of time.

We were very fortunate in securing the cooperation of the United States Coast and Geodetic Survey in the matter of constructing the tidal curves used in the present investigation. On the basis of the data in Table 1, curves representing the lunar equilibrium-tide at Delaware for the period from March 1, 1930, to July 1, 1932, were produced on the tide-predicting machine.

TABLE 1

Function f			(V_0+u) Jan. 1, 1930	Speed	Ampli- tude $\times$ f	Latitude- factor $\lambda = 40° 15'$ N	Amplitude $\times$ f $\times$ lati- tude-factor
Compo- nent	July 1, 1930	Apmli- tude					
M_2	0.968	0.4543	337.2	28.9841042	0.4398		0.2562
N_2	0.968	0.0880	161.4	28.4397295	0.0852		0.0496
Lunar L_2	1.022	0.0126	352.2	29.5284789	0.0129	$\cos^2 \lambda$	0.0075
$2N$	0.968	0.0117	345.6	27.8953548	0.0113	$= 0.5825$	0.0066
μ_2	0.968	0.0109	315.4	27.9682084	0.0106		0.0062
Lunar K_2	1.413	0.0393	189.2	30.0821373	0.0555		0.0323
O_1	1.165	0.1886	332.6	13.9430356	0.2197		0.2167
Q_1	1.165	0.0365	156.8	13.3986609	0.0425		0.0419
00	1.686	0.0081	216.6	16.1391017	0.0137	$\sin 2 \lambda$	0.0135
Lunar K_1	1.150	0.1812	4.6	15.0410686	0.2084	$= 0.9863$	0.2055
J_1	1.150	0.0149	180.4	15.5854433	0.0171		0.0169
M_1	1.312	0.0149	228.3	14.4966939	0.0195		0.0192
Mf	1.402	0.0783	212.0	1.0980331	0.1098	$(1-3 \sin^2 \lambda)/2$	-0.0138
Mm	0.887	0.0414	175.8	0.5443747	0.0367	$= -0.1261$	-0.0046

Note—The quantity f is a factor for adapting a mean amplitude to a particular time, and is given in Table 14, page 207, Schureman's "Manual of the harmonic analysis and prediction of tides."

The curves as received from Washington were in the form of three large rolls. They were six inches in width and of lengths determined by the scale of one-half inch to one hour. Two lines were drawn upon the rolls, namely, one the tidal curve itself, the other a horizontal line

at the height $y = 0$, interrupted by certain marks of identification. A double notch downward designated each point corresponding to midnight; single notches downward marked the other hour-points. Upward notches marked the times of the maxima and minima of the tidal curve. A scale was provided for reading off in feet the height of the oceanic tide, but this of course was meaningless as applied to an atmospheric tide. We used instead a purely arbitrary scale of thirty divisions engraved upon transparent celluloid. The lowest tidal readings were about 2, the highest about 26, on this arbitrary scale. A reading of 10 corresponded to zero tidal force or mean tidal level, but this point was felt to have no special significance in the case of an atmospheric tide. A scale of all positive values is to be preferred over one employing both positive and negative values when correlations are to be attempted.

Slightly over 3000 readings were made altogether. Each reading was entered, along with other data, upon a separate index-card. The times for which the readings were made are as follows, the selection of these particular times being governed by the availability of the radio data as explained later:

For the year 1930—Daily for the period March 1 to December 31 at 9:15 p. m. and at 9:45 p. m.

For the year 1931—Daily for the periods May 1 to August 31 at 8:15 p. m. and 8:45 p. m.; January 1 to December 31 at 9:15 p. m. and 9:45 p. m.; September 1 to December 31 at 10:15 p. m. and 10:45 p. m.; May 1 to August 31 at 12:30 a. m.; September 1 to December 31 at 12:37 a. m.; May 1 to May 31 at 1:00 a. m.; June 1 to December 31 at 1:15 a. m.; June 1 to July 31 and September 1 to December 31 at 1:45 a. m.

For the year 1932—Daily for the period January 1 to March 31 at 9:15 p. m., 9:45 p. m., 10:15 p. m., 10:45 p. m., 12:37 a. m., 1:15 a. m., and 1:45 a. m.

The intensity of radio reception has been determined regularly at the Perkins Observatory by a superheterodyne receiving-set in connection with automatic recording devices.[4] The signal-strengths of the incoming carrier-wave are measured continuously during the observing period, the units of measurement being microvolts in the receiving antenna. The transmitting-station employed was WBBM, Chicago, whose carrier-wave operates on a carefully regulated power-output and on a frequency of 770 kc/sec.

For the purpose of our investigation the radio record was divided into half-hour periods, with the exception of a 45-minute period from 12:15 to 1:00 a. m. The mean signal-strength for each period was entered upon the data-card corresponding to the middle of the period. This card also carried the reading of the tidal curve as previously explained. The reason is now obvious for the choice of the particular times given; the 9:15 cards represent the periods from 9:00 to 9:30, the 9:45 cards the periods from 9:30 to 10:00, the 12:37 cards the periods from 12:15 to 1:00, etc. In all, 1562 completed cards were obtained, for times well distributed throughout the period under consideration.

The extended studies of radio intensities at the Perkins Observatory have made possible the approximate evaluation of the "twilight-effect," that phenomenon whereby radio reception is found to be poorer during the hours immediately following sunset and immediately preceding

sunrise than during the hours near midnight, an effect superimposed upon the variations due to other causes, such as the solar cycle. Accordingly, the appropriate "twilight-factor" was entered upon each index-card directly below the value obtained from the radio record, and the two quantities were multiplied together. The resulting "corrected intensities" were used in the subsequent correlation.

The cards were sorted into groups in the order of increasing values of the tidal force. The first group consisted of values below 3.0, the second of values from 3.0 to 3.4, the third of values from 3.5 to 3.9, and so on. These groups were of greatly unequal sizes, a result which is at once evident from the nature of the tidal curve. As it was desirable to have the points of our correlation-curve of approximately equal weight, the data-cards, after being arranged in the order described above, were counted off into groups of 100 each, except for the last group of 62. This procedure gave us 16 groups of cards, each with a very small range of values of the tidal force. The individual values of the radio intensity were widely divergent, however, as radio reception is subject to all sorts of variations due to mechanical, electrical, and meteorological causes.

In order to smooth out these accidental variations, means were taken of both the tidal force and the radio intensity for each group, then running means of three groups at a time. These operations gave us the data shown in Table 2.

TABLE 2—*Average values radio intensity and tidal force for groups given ranges tidal force and three-group running means*

Group No.	Range tidal force	Average value		Running mean		
		Radio intensity	Tidal force	Group Nos.	Radio intensity	Tidal force
1	< 3.0	1034.52	2.307			
2	3.0– 3.4	839.24	3.960			
3	3.5– 3.9	1197.02	4.184	1, 2, 3	1023.59	3.484
4	4.0– 4.4	1212.20	4.602	2, 3, 4	1082.82	4.249
5	4.5– 4.9	1323.21	5.333	3, 4, 5	1244.14	4.706
6	5.0– 5.4	1489.89	5.848	4, 5, 6	1341.77	5.261
7	5.5– 5.9	1320.77	6.255	5, 6, 7	1377.96	5.812
8	6.0– 6.4	1204.07	6.845	6, 7, 8	1338.24	6.316
9	6.5– 6.9	982.52	7.528	7, 8, 9	1169.12	6.876
10	7.0– 7.4	1060.70	8.496	8, 9, 10	1082.43	7.623
11	7.5– 7.9	726.91	9.652	9, 10, 11	923.38	8.559
12	8.0– 8.4	771.66	10.999	10, 11, 12	853.09	9.716
13	8.5– 8.9	787.92	13.119	11, 12, 13	762.16	11.257
14	9.0– 9.4	885.65	15.655	12, 13, 14	815.08	13.258
15	9.5– 9.9	1144.69	18.851	13, 14, 15	939.42	15.875
16	10.0–10.4	1171.63	22.296	14, 15, 16	1067.32	18.934

A curve was plotted from these running means, using the tidal values as abscissae and the radio intensities as ordinates (Fig. 1). It was seen that the equation for the height of the equilibrium-tide is the same as the equation for the tidal force, except in the constant term. It follows, since our amplitude scale is arbitrary in any case, that the abscissae of Figure 1 may be interpreted either as tide-producing forces or as tidal heights.
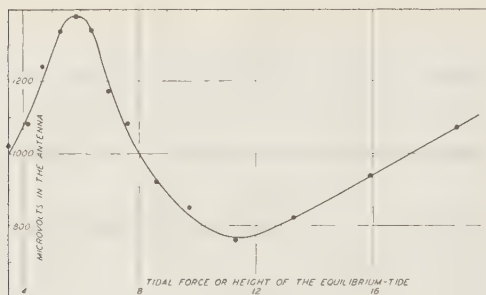
FIG. I—RADIO INTENSITY VERSUS LUNAR TIDAL FORCE

It is to be noted that on the adopted arbitrary scale the point 10 on the horizontal axis corresponds to zero tidal-force or mean tidal-level; also that these conditions obtain when the altitude of the Moon is approximately 36° either positive or negative. Negative tidal-forces (less than 10 on the scale of Fig. 1) correspond to altitudes less than 36°; positive tidal-forces (greater than 10) correspond to altitudes greater than 36°. The scale of altitudes cannot be given exactly on the same diagram, however, for the ratio of tidal force to altitude varies somewhat with the Moon's distance from the Earth. These relationships follow from a consideration of equation (1).

It is evident at once that Figure 1 does not represent a mere random scattering of points. It is evident also that it does not indicate a simple linear-relationship between tidal force and radio intensity over the entire range of the former. Interpreting the values along the horizontal axis of our graph as tidal heights rather than forces, we see that there are two critical heights, namely, one at about 5.8, the other at about 11.3. On this interpretation, as mentioned before, positive and negative values no longer have any physical significance. Our purely arbitrary scale, all positive, represents the height of atmospheric strata just as faithfully as the more conventional designations of plus and minus tides.

The curve (Fig. 1) indicates that the intensity of radio reception over the fixed distance increases with increasing tidal-height from the lowest levels recorded to the first critical point of 5.8 on the arbitrary scale. Thereafter there is a decrease of microvolts in the antenna with increasing values of the tidal force to a record critical value at 11.5. Any further lifting of the ionized layer with the higher values of tidal force again appears to result in increasing values in field-intensity. It would appear from a study of the graph, therefore, that the optimum conditions so far as the lunar effect is concerned prevail for a critical height corresponding to a tidal force of 5.8. As the distance from Delaware to Chicago is some 480 km, the effect of the ground-wave should be practically negligible.

Under certain general assumptions as to the characteristics of propagation of radio waves, the total attenuation Γ along a ray-path in the ionized layer is $\Gamma = \int \gamma \, ds$, where ds is the element of path traversed, and γ is the attenuation-coefficient. When the wave after being refracted again returns to Earth the total attenuation along the curved path in the ionized layer may be calculated as a function of frequency,

layer-height, and the electronic gradient at the apex of the ray-path. This has been expressed by Namba[18] as follows

$$\Gamma = A \left\{ \omega^2 \left[\cos^2 i_0 \ (2z/r_0) \right]^{3/2} / (\mathrm{d} N/\mathrm{d} z)_0 \right\}$$

where ω is the angular frequency, i_0 the angle of incidence at the Earth, z the height of the ionized layer, r_0 the radius of the Earth, and $(\mathrm{d}N/\mathrm{d}z)_0$ is the electronic gradient. The quantity A is a constant which depends on the form of electronic distribution.

In the application to the present problem, ω is constant (770 kc/sec for the station WBBM), and since the distance between Delaware and Chicago is small compared with r_0 we may write with fair approximation for $\cos^2 i_0$ the expression $[z^2/(z^2+d^2)]$, where d is the distance between the receiving and sending station. Hence the above expression becomes independent of i_0 and dependent upon the single variable z and the electronic gradient $(\mathrm{d}N/\mathrm{d}z)_0$. At a given value of z_0 corresponding to the mean night height of the Kennelly-Heaviside Layer we may then regard the electronic gradient as a variable depending upon the assumed tidal-effect due to the Moon. If this gradient is small corresponding to a condition approaching uniform distribution of electrons in a given shell of the ionized layer, the attenuation Γ will be large and we should expect low values in the measured field-intensities in the receiving antenna. With the increasing values of the tidal force the electronic gradient is disturbed and rises in value, thereby reducing the attenuation Γ until the value of the electronic gradient changes sign. A further rise in the tidal force would lift to the apex of the ray-path a
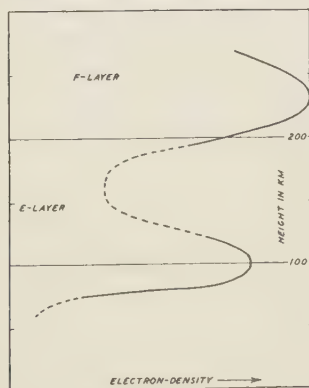
FIG. 2—PROBABLE DISTRIBUTION OF ELECTRON-DENSITY WITH ALTITUDE ABOVE THE EARTH'S SURFACE

region of lower electronic density (Fig. 2), thereby again increasing the attenuation until the second critical point is reached on the tidal curve of Figure 1 where the minimum field-intensity is recorded. A further increase in the value of the tidal force may be assumed to again raise the electronic density through the approach of the lower layer (Fig. 2) with a corresponding decrease in the attenuation, accounting for the

[18]S. Namba, General theory of the propagation of radio waves in the ionized layer of the upper atmosphere, Proc. Inst. Radio Eng., 21, 238-262 (1933).

rising value in field-intensity shown at the right-hand of the curve in Figure 1. Were tidal forces exerted by the Moon to attain still higher values than are represented, we should again expect a point of inflection followed by the approach of the curve of field-intensities to the x-axis.

An entirely different picture of the lunar effect may be obtained by analysis of the radio data which shall represent measured field-intensities as a function of the hour-angle and declination of the Moon. In the first and preliminary report by one of us, the correlation between intensities and lunar hour-angles was exhibited, but no attempt was then made to separate the data depending upon the declination of the Moon which is an important factor in tidal phenomena. It appeared profitable in the treatment of the more extended data represented in the present investigation to discover what correlations exist between the hour-angles of the Moon and radio intensities for three cases: First, when the Moon was south of the equator (declinations $-12°$ to $-28°$); second, when the Moon was in the region of the equator (declinations $-12°$ to $+12°$); and third, when the Moon was north of the equator (declinations $+12°$ to $+28°$). The results of this analysis are represented graphically in Figure 3. It will be observed that for the case where the
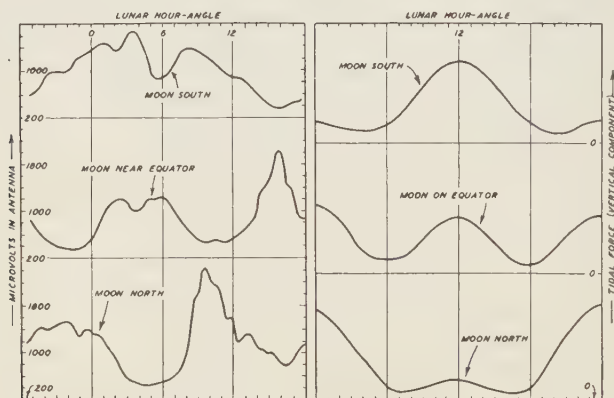
FIG. 3—CORRELATION-CURVES OF RADIO INTENSITIES WITH HOUR-ANGLE AND DECLINATION OF THE MOON
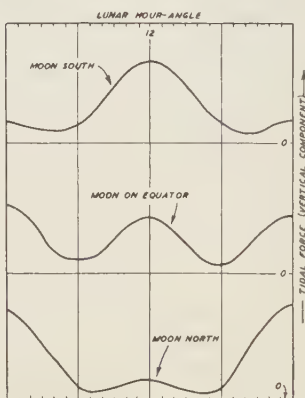
FIG. 4—CORRELATION-CURVES OF TIDAL FORCE VERTICAL COMPONENT WITH HOUR-ANGLE AND DECLINATION OF THE MOON

Moon is south of the equator there is a general rise of signal-strength until the maximum value is reached for a lunar hour-angle of about 3^h, the minimum value occurring at 15^h. When the Moon is north of the equator the minimum value occurs at about 4^h, or near the time of maximum for the uppermost curve. The apparent inversion of phase is characteristic of a tidal effect for a point at mid-latitudes. The form of the curve when the Moon is in the region of the equator is suggestive of a semi-diurnal tide. For comparison purposes the theoretical equilibrium-tides as represented by the vertical component of the tidal force at latitude $40°$ is shown in Figure 4. For the case when the Moon is on the equator, the semi-diurnal tides are practically equal. When the Moon is south of the equator a primary diurnal maximum occurs

at 12^h and a small secondary maximum at 0^h. When the Moon is north of the equator it will be observed that the primary diurnal maximum occurs at 0^h and the secondary maximum at 12^h is so trivial as to give the appearance of mid-minimum for the diurnal effect, thus producing an apparent reversal in phase as the Moon passes from the south side to the north side of the equator. It is, of course, too much to hope that a tidal effect in the ionized layer would follow very closely the theory of equilibrium-tides. It appears, therefore, all the more significant that we find certain marked correspondences between the curve of radio intensities and those of the equilibrium-tides for latitude 40° (Fig. 4).

The distribution of ions and electrons in the Earth's atmosphere must be far from uniform on account of the effect of the Earth's magnetic field. As the electrons tend to flow in the direction of the magnetic poles of the Earth, we should expect a higher electron-density for a given altitude in the region of higher latitudes than would be the case if uniform distribution were to exist. One would in effect, therefore, expect to find an apparent lowering of the Kennelly-Heaviside Layer as one progresses from the equator poleward. The diurnal equality in the tides should therefore be even more pronounced at higher latitudes. The effect of the rotation of the Earth would further complicate the situation, and it appears difficult to say from our present information how much lag could be expected in the formation of a tide as the result of the Moon's action. A further accumulation of observational data well distributed over the globe is needed to attack the problem on a world-wide scale.

One puzzling deduction from the curves of correlation between radio intensity and lunar hour-angle concerns the magnitude of the change in the intensity represented. Investigations by Kenrick and Pickard give evidence for a lunar effect with considerably less variation between the extremes than is represented in Figure 3. It appears, however, that a partial explanation of the discrepancy results from the fact that in the investigations of Kenrick and Pickard no attempt was made to take into account the changing declination of the Moon in producing the observed effects, nor does it appear that the effect of twilight was eliminated from the data gathered in the early evening hours which should be appreciable in Boston during the summer season. Reference again to Figure 3 will make it evident that if the curves for the different declinations of the Moon were combined into a single curve of hour-angles and radio intensities, the differences in phase of the three curves would so combine as to produce very considerably the total variation between maximum and minimum in the intensity-curve.

One may now inquire as to any reasonable explanation for any considerable change in the altitude of the Kennelly-Heaviside Layer that should depend upon the movements of the Moon. It does not appear reasonable that the relatively small gravitational tide in the Earth's atmosphere which changes the barometric pressure by less than 1/400 of one per cent could account for a sufficient change in altitude in the ionized layer to produce such marked changes in reception. If, on the other hand, we were to suppose that the Moon itself is a source of ionization, we might have some grounds for accounting for the necessary changes in the electron-density of the ionosphere that appear to accompany the Moon as it passes over the observer's sky.

Recently Rizzo[19] has reported the existence of gamma-radiations in a chamber buried 20 meters in the underlying volcanic tufa below the Institute of Terrestrial Physics, at Naples, the intensity of these gamma-radiations exceeding even that of pitchblend. One may speculate as to the plausibility of gamma-radiations emanating from the volcanic surface of the Moon in sufficient amount to appreciably affect the electron-density of the Earth's upper atmosphere. One may further have to consider the part which resonance may play in the changing electron-density of the conducting layers. If the electrical character-istics of the ionosphere at a given critical height are such as to provide a natural period for motions of ionic clouds, which should be com-parable with the lunar day or some harmonic of it, then a small effect of the Moon might greatly amplify any tidal effect through the close correspondence of a forced lunar period upon a natural free-period of motion. We must content ourselves for the moment with the presenta-tion of such observational facts as have thus far been determined, and with the suggestion of such hypotheses as may be reasonably profitable to entertain until a more complete knowledge of the behavior of the ionosphere and longer and more complete records of observational data are obtained.

[19]G. B. Rizzo, Rend. Accad. Sci. Fis. e Mat., Naples (1932); see also note on Gamma-rays of volcanic tufa, Nature, **132**, 356 (1933).

HARVARD UNIVERSITY,
  Cambridge, Massachusetts
    May 1934

LETTERS TO EDITOR

PROVISIONAL SUNSPOT-NUMBERS FOR MARCH TO MAY, 1934

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	Mar.	Apr.	May	Day	Mar.	Apr.	May
1	. .	0	7	17	0	32	. . d
2	0	11	0	18	7	29	41
3	0	12	0	19	0	22	46
4	7	9	M . . c	20	0	21	37^a
5	0	8	17	21	0	22	29
6	$E\ 7^c$	0	21^a	22	0	18^b	34
7	9	0	26	23	0	16	33^a
8	19	0	34	24	0	19	23
9	22^a	. .	23	25	7	11	19
10	12	0	19	26	7	10	17
11	15	0	10	27	0	16	9
12	7	0	7	28	0	14	16
13	0	0	15^d	29	7	7	8
14	0	7^d	21	30	7	0	0
15	0	21	26	31	0		0
16	0	33	25 ·				
				Means..	4.4	11.7	19.4
				No. days	30	29	29

Mean for quarter January to March, 1934: 5.2 (82 days)

aPassage of an average-sized group through the central meridian.
bPassage of a larger group through the central meridian.
cNew formation of a large or average-sized center of activity: E, on the eastern part of the Sun's disc; W, on the western part; M, in the central zone.
dEntrance of a large or average-sized center of activity on the east limb.

Zürich, Switzerland   W. Brunner

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1]

The data for terrestrial magnetism, sunspots, solar constant, and auroræ are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Electricity, (2) the type featuring the day other than normal by the letters b, p, o, and i for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N = k\ (10g + s)$, where k for Mount Wilson is about 0.7

[1]For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931); **37**, 85-89, 189-192, 408-411, and 484-487 (1932); **38**, 60-63, 148-151, 262-265, 335-339 (1933), and **39**, 73-77.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in footnotes to the table.

The present values of the solar constant published in these tables are from Table Mountain, California, and have not so great weight as those formerly furnished from Montezuma. The columns headed solar constant show (1) the value in calories of the solar constant, and (2) by letters *s*, *f*, and *u* whether the determination was satisfactory, fair, or unsatisfactory, respectively.

Under the general heading of aurora in the table, the first column gives the character of the day: 0 indicates no aurora; 1, faint; 3, moderate; 5, strong; 7, brilliant; and 9, no observation or no observations possible on account of cloudiness. The second column gives the number of hours during which aurora was present. The third column indicates the amount of sky covered by cloud on a scale of 0-10, where 0 means cloudless, and 10 completely overcast.

Summary American URSI daily broadcas

		January																	February					
Date	Magnetism			Sun-spot		Solar constant		Aurora											Magnetism			Sun-spot		Solar constant
	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.	Char.	Duration	Cloudiness	Form		Area covered	Av. altitude	Position	G.M.T.greatest distur.			Char.	Type	G. M. T. begin. distur.	Groups	No.	Value
			h *m*			cal.			hrs		With-out rays	With rays				*h*					*h* *m*			cal.
1	0	...	.. ..	...	...	.....	...	3	5	0	HV	RB	0.2	30	W-N-E	9			0	...	.. ..	1	3	1.953
2	1	*i*	16 00	0	0	1.959	*s*	3	5	0	HV	RV	0.2	45	W-N-E	10			0	...	.. ..	1	1	1.959
3	0	...	.. ..	0	0	1.955	*f*	1	3	0	HV	.....	0.2	20	NW-N-NE	8			0	...	.. ..	1^b	1^b	.....
4	0	...	.. ..	0	0	1.960	*f*	1	5	2	HV	.....	0.2	20	NW-N-NE	9			0	...	.. ..	0	0	.....
5	0	...	.. ..	0	0	1.954	*s*	9	...	10	.....	.....			.....				0	...	.. ..	1^b	5^b	.....
6	0	...	.. ..	0	0	1.953	*f*	0	...	9	.....	.....			.....	..			0	...	.. ..	2^b	6^b	1.963
7	0	...	.. ..	0	0	1.941	*f*	1	1	6	HV	.....	0.2	45	NW-N-NE	11			0	...	.. ..	2^b	13^b	.....
8	0	...	.. ..	0	0	1.957	*f*	1	2	7	HB	.....	0.2	18	NW-N-NE	10			0	...	.. ..	2^a	6^a	1.961
9	0·	...	.. ..	0	0	1.951	*s*	1	1	9	DS	.....	0.2	20	NW	10			1	...	.. ..	1^a	1^a	.....
10	0	...	.. ..	0	0	.....	...	9	...	10	.....	.....			.....				0	...	.. ..	1^a	1^a	1.951
11	0	...	.. ·.	0	0	.....	...	3	9	0	HV	.....	0.2	20	NW-N-NE	11			0	...	.. ..	1^a	1^a	1.941
12	0	...	.. ..	1^a	5^a	1.961	*f*	1	6	0	HV	RB	0.2	15	NW-N-E	11			0	...	.. ..	1^a	2^a	1.942
13	0	...	.. ..	1^a	9^a	1.955	*s*	1	3	0	HV	.....	0.2	15	NW-N-E	10			0	...	.. ..	1^a	1^a	.....
14	0	...	.. ..	1^a	16^a	1.966	*s*	3	8	0	HV	.....	0.2	12	NW-N-E	9			0	...	.. ..	1^a	4^a	1.962
15	1	...	.. ..	1^d	10^a	1.936	*u*	1	6	0	HV	.....	0.6	55	W-N-E	10			0	...	.. ..	..	..	.....
16	1	...	.. ..	1^a	5^a	1.945	*s*	3	6	0	HV	R	0.6	30	NW-N-E	9			0	...	...	.. ..	3^a	1.939
17$_1$	0	...	.. ..	1^b	2^a	1.949	*u*	9	...	10	.....	.....			.....				1	*i*	8 00	1^a	4^a	1.954
18	0	...	.. ..	1^a	1^a	1.962	*f*	1	3	7	HV	R	0.4	50	NW-N-NE	13			1	...	.. ..	1^a	4^a	.....
19	0	...	.. ..	0	0	1.959	*f*	1	·9	0	HV	.....	0.4	15	NW-N-NE	12			0	...	.. ..	..	..	.....
20	0	...	.. ..	0	0	.....	...	3	9	0	HV	.....	0.4	25	NW-NE-E	9			0	...	.. ..	0	0	1.956
21	0	...	.. ..	0	0	1.970	*u*	1	7	0	HV	.....	0.6	20	NW-N-E	14			0	...	...	.. ..		
22	0	...	\. ..	0	0	1.955	*s*	1	4	0	HA	.....	0.2	15	NW-N-NE	12			0	*b*	2 30	0	0	1.958
23	1	...	.. ..	0	0	1.958	*u*	1	6	3	HV	RB	0.6	30	NW-N-E	14			0	...	.. ..	..	..	.....
24	0	...	.. ..	0	0	1.944	*u*	1	4	0	HV	.....	0.2	45	NW-N-NE	8			0	...	.. ..	..	..	.....
25	0	...	.. ..	0	0	1.951	*s*	1	1	0	HA	.....	0.2	10	NW-N-NE	8			0	...	.. ..	..	..	.....
26	0	...	.. ..	0	0	1.958	*s*	1	1	0	HA	.....	0.2	12	NW-N-NE	10			0	...	...	.. ..		
27	0	...	.. ..	0*	0*	1.954	*f*	1	1	1	HA	.....	0.2	8	N-NE	8			0	...	.. ..	0*	0*	.....
28	0	...	.. ..	0	0	1.955	*s*	0	...	7	.....	.....			.....				0	...	.. ..	0	0	1.946
29	0	...	.. ..	1^b	1^b	1.965	*s*	1	1	8	.....	RB	0.2	20	NW-N	10								
30	0	...	.. ..	1^b	4^b	1.964	*s*	1	1	7	HB	.....	0.2	15	NE	12								
31	0	...	.. ..	1	3	1.956	*f*	1	3	4	HA	.....	0.2	17	NW-N-E	9								
Mean	0.1	...	.	0 3	1 8	1.955	..	2.1	4.2	3	.	.....			....	10			0.1	..	..	1 0	2.8	1.953

Greenwich mean times for endings of storms: 5^b, Jan. 3; 4^b, Mar. 11.
^{a}Old cycle. ^{b}New cycle; values are revisions of those originally broadcast. ^{c}One old, one new cycle.
*A revision of original value broadcast.

Columns four and five describe by letters the form of the aurora, column four indicating forms without ray structure and column five, forms with ray structure. The letters employed are the same as those used in the Photographic Atlas of Auroral Forms published by the International Geodetic and Geophysical Union, Oslo, 1930, so far as it was possible to use those letters. For forms without ray structure *HA* indicates homogeneous quiet arcs; *HB*, homogeneous bands; *PA*, pulsating arcs; *DS*, diffuse luminous surfaces; *PS*, pulsating surfaces; *G*, feeble glow; *HV*, varied forms; *HF*, flaming aurora, and *HVF*, varied forms with flaming. For forms with ray structure *RA* indicates arcs; *RB*, bands; *D*, draperies; *R*, rays; *C*, corona; *RV*, varied forms; *RF*, flaming aurora; and *RVF*, varied forms with flaming.

Column six gives the maximum area of sky covered in tenths of the whole sky, column seven the average altitude in degrees, and column eight the general position of the aurora, being reckoned for included positions in a clockwise direction with *Z* representing zenith and *A* the whole sky. The final column gives the Greenwich mean hour of the

mic data, January to March, 1934

	February							March																	Date
	Aurora							Magnetism				Sun-spot		Solar constant		Aurora									
Cloudiness	Form		Area covered	Av. altitude	Position	G.M.T. greatest distur.	Char.	Type	G. M. T. begin. distur.		Group	No.	Value	Char.	Char.	Duration	Cloudiness	Form		Area covered	Av. altitude	Position	G.M.T. greatest distur.	
	With-out rays	With rays							h	m								With-out rays	With rays					
				°		h			h	m			cal.			hrs					°		h	
9	HB		0.2	5	NE	10	0				0	0	1.940	f	9		10							1
6							0				0	0			9		10							2
1	HV	R	0.2	20	NW-N-E	12	0				0	0			9		10							3
1	HA		0.4	22	NW-N-E	9	0				1	1	1.960	f	0		0							4
9							1	o			0	0	1.956	s	1	4	6	HV		0.2	75	W-N-E	8	5
1	HV		0.4	25	NW-N-E	13	1				1	1			5	9	0	HV	R	0.6	75	W-NE-SE	8	6
0	HV	RB	0.4	15	NW-N-E	13	1	i			2ᵈ	7ᵈ			5	9	0	HV	R	0.6	75	W-NE-E	9	7
2	HV		0.2	15	NW-N-NE	9	1				2ᵉ	7ᵉ	1.951	s	1	5	4	HB		0.2	15	NW-N-NE	8	8
4	HV	C	0.4	60	W-NE-SE	12	0				2ᶠ	9ᶠ	1.955	s	1	1	7	HB	RB	0.2	35	NW-N-E	12	9
3	HV		0.6	50	NW-NE-E	8	9				2ᵍ	7ᵈ			1	1	8	HB		0.2	20	NW-N-NE	10	10
8	G		0.4	60	NW-N-E	15	0	b	2	00	2ᵍ	4ᶜ			9		9							11
10							0				2ᵇ	8ʰ			1	1	6	HB		0.2	28	N-NE-E	9	12
7	HB		0.2	10	W-N-E	8	0				1	3	1.948	f	1	2	4	HB	RB	0.2	30	NW-N-E	12	13
10							0				0	0	1.945	f	1	5	0	HV		0.2	15	NW-N-E	10	14
0	HV		0.4	50	W-N-E	12	0				0	0			3	9	0	HV	RB	0.4	35	W-N-SE	11	15
0	HV	RV	0.8	75	W-N-SE	12	0				0	0	1.937	f	1	1	7	HA		0.2	25	N-NE	7	16
8	HV	RB	0.4	80	W-N-E	8	0				0	0			1	3	3	HV		0.2	45	W-N-E	9	17
0	HV	RV	0.8	50	W-N-SE	10	0				0	0	1.957	u	1	6	1	HV		0.4	40	NW-N-E	10	18
2	HV		0.2	15	NW-N-E	10	0				0	0	1.951	f	0		7							19
0	HV	RV	0.6	20	W-N-E	9	0				0	0	1.955	s	1	2	6	HB		0.2	25	NW-N-NE	13	20
0	HV		0.2	12	NW-N-NE	10	0				0	0	1.943	u	1	6	0	HV	RB	0.2	30	NW-N-E	10	21
4	HV		0.2	18	NW-N-NE	8	0				0	0			0		1							22
4	HA	R	0.2	10	N-NE-E	10	1				0	0			9		10							23
4	HA	RB	0.2	14	NW-NE-SE	13	0				0	0	1.958	u	1	4	1	HA		0.2	15	N-NE	8	24
9							1				1	2	1.940	s	9		10							25
6	HA		0.2	8	N-NE	11	0				1	1	1.957	f	9		10							26
3	HB		0.2	10	N-NE-E	12	0				0	6			1	1	1	HB		0.2	12	NW-N-NE	10	27
10							0				0	0			1	2	5	HB		0.2	12	NW-N-E	11	28
							1				1ᵇ	2ᵇ			1	3	1	HV		0.2	25	NW-N-NE	10	29
							0				0	0			1	2	0	HB		0.2	10	NW-N-E	12	30
							1				0	0			1	3	0	HV	RB	0.2	40	NW-N-E	8	31
4						11	0.3				0.6	1.5	1.950		3.0	3.8	4						10	Mean

ᵇne new, six old cycle. ᶜTwo new, five old cycle. ᶠOne new, eight old cycle. ᵍThree new, six old cycle.

Kennelly-Heaviside Layer heights, Washington, D. C., January to March, 1934

Date	Frequency	Nearest hour G.M.T.	Height	Date	Frequency	Nearest hour G.M.T.	Height
1934	kc/sec	h	km	1934	kc/sec	h	km
Jan. 3	2,200	17	120	Jan. 31	5,800	17	340
" "	2,500	17	120	" "	6,000	17	380
" "	2,700	17	No value obtained	Feb. 7	2,500	17	140
" "	2,730	17	220	" "	2,760	17	180
" "	4,000	17	280	" "	2,860	17	140, 260
" "	5,200	17	300, 370	" "	2,920	17	190
" "	6,000	17	350, 660	" "	2,980	17	350
" "	7,000	17	130, 820	" "	3,400	17	210
" 10	2,530	17	130	" "	4,030	17	330
" "	2,750	17	200	" "	4,300	17	240, 280, 380
" "	2,870	17	170	" "	5,000	17	280
" "	2,950	17	260	" "	5,400	17	300
" "	3,050	17	190	" "	5,700	17	350
" "	3,470	17	290	" "	6,000	17	300
" "	4,400	17	240	" "	6,200	17	330
" "	5,000	17	270	" "	6,300	17	720
" "	6,000	17	270	" "	6,500	17	720
" "	6,300	17	280	" "	6,600	17	No value obtained
" "	6,400	17	300	" 14	2,550	17	130
" "	6,500	17	400	" "	3,050	17	140, 250
" "	6,600	17	680	" "	3,450	17	200
" "	6,800	17	670	" "	3,950	17	320
" "	7,300	17	720	" "	4,400	17	240, 290
" "	7,400	17	No value obtained	" "	5,000	17	290
" 17	2,500	17	140	" "	6,000	17	310
" "	2,790	17	180	" "	6,200	17	300, 380
" "	2,800	17	260	" "	6,800	17	440, 680
" "	3,000	17	200	" 21	2,900	17	150
" "	3,830	17	290	" "	3,000	17	240
" "	4,400	17	270	" "	3,160	17	210
" "	5,000	17	280	" "	4,150	17	350
" "	6,000	17	300	" "	4,600	17	280
" "	6,500	17	310	" "	5,200	17	330
" "	6,600	17	350	" "	6,400	17	280, 330
" "	6,700	17	700	" "	6,800	17	450, 620
" "	6,900	17	730	" "	6,900	17	670
" 24	2,700	17	120	" 28	3,000	17	No value obtained
" "	2,850	17	120, 230, 360	" "	3,280	17	190
" "	2,950	17	120, 230, 430	" "	3,700	17	470
" "	3,050	17	120, 230, 310	" "	3,800	17	300
" "	3,600	17	230	" "	4,400	17	290
" "	3,900	17	340	" "	5,000	17	280
" "	4,400	17	290	" "	6,000	17	270
" "	4,600	17	110, 300, 410	" "	6,900	17	300
" "	5,400	17	110, 300, 580	" "	7,500	17	340
" "	6,200	17	210, 300, 720	" "	7,600	17	350
" "	6,900	17	220, 770	" "	7,800	17	550
" "	7,000	17	No value obtained	" "	7,900	17	790
" 31	2,650	17	160	Mar. 7	2,500	17	No value obtained
" "	2,800	17	220	" "	2,950	17	310
" "	2,900	17	190	" "	3,050	17	200
" "	3,010	17	260	" "	3,500	17	220
" "	3,800	17	280	" "	4,080	17	440
" "	3,970	17	380	" "	4,400	17	330
" "	4,400	17	310	" "	4,600	17	250, 350
" "	5,000	17	300	" "	4,800	17	300, 360
" "	5,600	17	320	" "	5,000	17	360

*Kennelly-Heaviside Layer heights, Washington, D. C., January to March, 1934 —*Concluded

Date	Frequency	Nearest hour G.M.T.	Height	Date	Frequency	Nearest hour G.M.T.	Height
1934	*kc/sec*	*h*	*km*	*1934*	*kc/sec*	*h*	*km*
Mar. 7	6,000	17	340	Mar. 21	3,280	17	240
" "	6,500	17	340	" "	3,400	17	200
" "	6,600	17	360	" "	4,100	17	400
" "	6,700	17	470	" "	4,500	17	310
" "	6,800	17	No value obtained	" "	4,900	17	570
" 14	2,550	17	130	" "	5,100	17	640
" "	3,160	17	140	" "	5,300	17	390
" "	3,200	17	220	" "	5,400	17	430
" "	3,320	17	200	" "	5,900	17	390
" "	4,000	17	280	" "	6,000	17	400
" "	4,270	17	330	" "	6,100	17	No value obtained
" "	4,400	17	310	" 28	2,800	17	140
" "	5,000	17	250	" "	3,270	17	260
" "	6,000	17	300	" "	3,670	17	210
" "	6,600	17	310	" "	4,230	17	390
" "	6,800	17	330	" "	4,800	17	300
" "	7,000	17	390	" "	5,500	17	350
" "	7,200	17	No value obtained	" "	5,700	17	350, 450
" 21	2,750	17	150	" "	5,800	17	350, 520
" "	3,000	17	No value obtained	" "	6,600	17	400
" "	3,100	17	220	" "	6,700	17	No value obtained
" "	3,240	17	170				

observed greatest display in the preceding 24 hours of the Greenwich day.

The table of Kennelly-Heaviside Layer heights is self-explanatory.

Beginning January 1, 1934, the magnetic information for the *URSI* gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, there will be a slight difference in time. Instead of the data covering the 24 hours ending 7 A. M., 105° west meridian mean time, the time covered will be the 24 hours ending at 8 A. M., 75° west meridian mean time, or one hour earlier.

DEPARTMENT OF TERRESTRIAL MAGNETISM,   C. C. ENNIS
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, JANUARY, FEBRUARY, AND MARCH, 1934

The diurnal range in H at Mount Wilson exceeded 100γ on February 9, February 16, and March 5, but the variations on these days were not classed as magnetic storms.

Thirteen spot-groups were observed in the first quarter of 1934, five belonging to the waning cycle and eight to the new cycle. The increasing activity of the new cycle in the high solar latitudes indicates that the phase of minimum activity is probably past.

	March 1934								February 1934								January 1934								
Day	Mag'c char.	No. groups	HaD B	HaD A	HaB B	HaB A	K₂ B	K₂ A	Mag'c char.	No. groups	HaD B	HaD A	HaB B	HaB A	K₂ B	K₂ A	Mag'c char.	No. groups	HaD B	HaD A	HaB B	HaB A	K₂ B	K₂ A	
Mean	0.3	0.6	0.0	0.3	0.1	0.4	0.2	0.4	0.2	0.9	0.0	0.0	0.6	1.1	0.6	1.0	0.1	0.3	0.0	0.1	0.0	0.1	0.0	0.1	

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PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1934[1]

(Latitude 57° 03'.0 N.; longitude, 135° 20'.1 or 9ʰ 01ᵐ.3 W. of Gr.)

The only storm of importance occurred on March 5. The storm was preceded by a gentle but gradually increasing disturbance beginning about 13ʰ, March 4, Greenwich mean time. On March 5, *D* and *H* increased very suddenly at 7ʰ 45ᵐ and *Z* began to increase about 7ʰ 52ᵐ. All reached their maximum values within a few minutes and their minimum values about an hour later. The values were about normal again by 13ʰ but the record continued disturbed for several days. The ranges were: *D*, 118'; *H*, 660γ; *Z*, 466γ.

JOHN HERSHBERGER, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1934[1]

(Latitude 38° 44'.0 N.; longitude 76° 50'.5 or 5ʰ 07ᵐ.4 W. of Gr.)

There were no magnetic storms recorded during the first quarter of 1934.

GEO. HARTNELL, *Observer-in-Charge*

HUANCAYO MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1934

(Latitude 12° 02'. 7 S.; longitude 75° 20'.4 or 5ʰ 01ᵐ W. of Gr.)

Greenwich mean time				Range		
Beginning		Ending		Decl'n	Hor. int.	Ver. int.
1934	h m	d h m		'	γ	γ
Mar. 4	10 20	7 22 57		6.4	266	35

March 4-8—A disturbance, which lasted from March 4 to 8, was not of a very marked nature, the principal characteristic being the rapid oscillatory-motions of relatively small amplitude. The disturbance began quietly on March 4 at 10ʰ 20ᵐ G.M.T., with oscillations of small amplitude. As the maximum was approached at 14ʰ the violence of the motions increased but not so strongly as not to record. The normal minimum was reached by a succession of descending bays at 21ʰ 27ᵐ March 4 and was lower than usual. Disturbed conditions, the principal characteristics of which were lowered ordinates and oscillatory-motions, particularly around the time of maximum and minimum, then persisted until March 7. The maximum of March 7 was considerably flattened and the minimum thereby obscured.

March 10-11—This disturbance was a minor one. The traces were irregular and the ordinates slightly depressed, while the maximum of March 10 was somewhat deformed by a sharp drop from 19ʰ 32ᵐ to 20ʰ 00ᵐ; otherwise the traces contained nothing of moment.

J. E. I. CAIRNS, *Observer-in-Charge*

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

WATHEROO MAGNETIC OBSERVATORY

JANUARY TO MARCH, 1934

(Latitude 30° 19'.1 S.; longitude 115° 52'.6 or 7 ʰ 43ᵐ.5 E. of Gr.)

March 4-8—A moderate disturbance began March 4 at 13 ʰ 19ᵐ G.M.T., with sudden small oscillations in all three elements, the declination showing a sudden decrease of 1' of westerly declination, the horizontal intensity an increase of 3γ, and the vertical intensity a decrease of about 3γ. These small oscillations continue for about 20 minutes of time, after which the traces show leisurely movements of larger amplitude. The minimum value of horizontal intensity occurred March 5 at 8 ʰ 08ᵐ when the force was about 100γ below its normal value. The leisurely movements continued until 16 ʰ on March 8, a period of small sharp oscillations being noteworthy, especially on the horizontal-intensity trace, between 8 ʰ 50ᵐ and 9 ʰ 20ᵐ on March 6.

March 10-11—A small disturbance began with a slow commencement at G.M.T. 2 ʰ 14ᵐ on March 10, shown as a decrease in all three elements (declination 1', horizontal intensity 3γ, and vertical intensity 4γ) occupying about three minutes of time. A small wave in all three elements having its peak at about 11 ʰ 40ᵐ on March 10 was the only other noteworthy feature of the disturbance, which ended at about 20 ʰ on March 11.

W. C. PARKINSON, *Observer-in-Charge*

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[Plate 3]

J. P. vander Stok

SUR QUELQUES ERREURS SYSTÉMATIQUES D'UNE BALANCE MAGNÉTIQUE

PAR JOHANNES OLSEN

Résumé—La note ci-après est une analyse d'une balance magnétique dont l'axe de rotation et l'axe magnétique ne sont pas horizontaux. Il y est montré que les erreurs qui en suivent, ont pour effet que la marche diurne de la déclinaison et celle de l'intensité de la force horizontale déforment l'enregistrement de la marche diurne de l'intensité de la force verticale. On déduit des formules pour la réduction des sources d'erreur en question.

Abréviations

ϵ—l'angle que l'axe magnétique de l'aimant est tourné de sa position horizontale (nombre abstrait)

$\underline{\epsilon}$—le même angle mesuré en minutes

η—l'inclinaison de l'axe de rotation de l'aimant (nombre abstrait)

$\underline{\eta}$—le même angle mesuré en minutes

P—la pesanteur de l'aimant (C. G. S.)

M—le moment magnétique (10^5 C. G. S.)

Z—la force verticale magnétique en γ (10^{-5} C. G. S.)

P_b—le pôle boréal de l'aimant

N, S, E, W—nord, sud, est et ouest magnétique

$\triangle D, \triangle H, \triangle Z$—les accroissements en minutes et en γ respectivement de D, H, et Z

$\triangle D_{mm}, \triangle H_{mm}, \triangle Z_{mm}$—ordonnées en millimètres de l'enregistrement de D, H, et Z

Z_o—la valeur de base de l'enregistrement de Z

a_D, a_H, a_Z—les valeurs d'échelle en minutes/mm et γ/mm des variomètres de D, H, et Z

$(1/s)$—la valeur d'échelle de l'aimant en γ/minute

*indique dans les tableaux "à peu près un demi"

Dans la note présente sera montré comment les lectures ou les enregistrements d'une balance magnétique seront réduits dans les cas où l'axe de rotation ou l'axe magnétique de l'aimant ne se trouvent pas dans le plan horizontal.

Nous allons démontrer que dans ces cas-là les lectures de la balance contiennent des termes dépendants des variations de H et de D. L'analyse en est importante surtout pour l'étude approfondie de la marche diurne de Z, car, dans ce but, il faut en premier lieu éliminer tout effet de la marche diurne de H et D.

Il va sans dire que l'effet de l'inclinaison de l'axe de rotation restera toujours négligeable si la balance a été bien ajustée dès le début, tandis que l'inclinaison de l'axe magnétique de l'aimant n'est zéro que dans certains cas.

Considérons d'abord un aimant qui n'est pas compensé de l'effet de la température. Supposons la force verticale Z constante et soit l'axe magnétique horizontal pour une certaine température t_o. Appelons ϵ l'angle que fait l'axe magnétique avec le plan horizontal en cas d'une température autre que t_o; cet angle est proportionnel à la sensibilité de l'aimant.

Voici d'abord, pour fixer les idées, quelques exemples numériques pour les deux cas spéciaux où le pôle boréal (P_b) de l'aimant est dirigé vers le nord magnétique, N, ou vers l'est magnétique, E (ou l'ouest magnétique), respectivement.

Soit $\epsilon = 0$ pour $t_\mathrm{o} = 20°$ et $Z = Z_\mathrm{o}$, et considérons pour le moment Z_o comme la valeur de base de l'enregistrement.

Désignons par a_Z la valeur d'échelle (γ/mm) de la balance et par $\triangle Z_{mm}$ l'ordonnée en mm de l'enregistrement de Z; on se borne, en général, à se servir de l'expression

$$Z = Z_\mathrm{o} + a_Z \triangle Z_{mm} + \xi (t - 20) \tag{1}$$

où ξ est l'effet de température.

Mais nous montrerons plus tard (11) que la vraie valeur de Z (quand la distance de la balance au papier photographique est 172 cm) est

$$Z = Z_\mathrm{o} + a_Z \triangle Z_{mm} + [(Z - Z_\mathrm{o})/3438\ a_Z]\ \triangle H + \rho\ \triangle H + \xi (t - 20) \tag{2}$$

quand P_b est dirigé vers N, et

$$Z = Z_\mathrm{o} + a_Z \triangle Z_{mm} + [H(Z - Z_\mathrm{o})/3438^2\ a_Z]\ \triangle D + \delta\ \triangle D + \xi (t-20) \tag{3}$$

quand P_b est dirigé vers E.

Dans ces équations $\triangle H$ et $\triangle D$ sont des écarts (en γ et en minutes respectivement) avec des valeurs fixes de H et de D. ρ et δ sont des facteurs dépendantes de t et de a_Z. Les valeurs ρ et δ calculées par des formules (9, 10, et 14) sont données dans le tableau 1 comme des fonctions de t et de a_Z. Pour ce calcul, on a compté l'effet de température à $12\gamma/C°$ (valeur approximative d'un aimant monade quand la force verticale est de $50000\ \gamma$ env.).

TABLEAU 1

| t | P_b vers N Le Facteur ρ dans l'Eq. (2) pour $a_Z =$ | | | P_b vers E Le Facteur δ dans l'Eq. (3) | | | | | |
| | | | | pour $H = 10000\gamma$ et $a_Z =$ | | | pour $H = 30000\gamma$ et $a_Z =$ | | |
	$5\gamma/\mathrm{mm}$	$10\gamma/\mathrm{mm}$	$15\gamma/\mathrm{mm}$	$5\gamma/\mathrm{mm}$	$10\gamma/\mathrm{mm}$	$15\gamma/\mathrm{mm}$	$5\gamma/\mathrm{mm}$	$10\gamma/\mathrm{mm}$	$15\gamma/\mathrm{mm}$
20°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.007	0.004	0.002	0.020	0.010	0.007	0.061	0.030	0.020
0	0.014	0.007	0.005	0.041	0.020	0.014	0.122	0.061	0.041
−10	0.021	0.010	0.007	0.061	0.031	0.020	0.183	0.092	0.061

On voit de ce tableau que dans le cas P_b vers N, $a_Z = 5\gamma/$mm et $t = -10°$ on a $\rho = 0.021$ c'est-à-dire que, si H croît de $50\,\gamma$ la valeur de Z trouvée par l'équation (1) sera à corriger par $50 \times 0.021 = 1\gamma$. Si encore $(Z - Z_0)$ croît de 10 mm (50γ), il faut en outre additionner $(10/3438)\,50 = 0.1\gamma$. Une variation annuelle de $30°$C est tout à fait possible à une station arctique, et si l'on ne corrige pas les valeurs trouvées pour Z, la variation enregistrée de Z contiendra à $-10°$C une marche diurne fausse correspondante à la marche diurne de H multipliée par 0.021. A Godhavn, cette correction monte jusqu'à 1.5γ. Pour $a_Z = 10$, la correction n'est que la moitié.

Ajoutons que les balances où la compensation de l'effet de la température est obtenue par une compensation optique, se comportent comme des balances munies d'aimants non compensés.

Pourvu que la balance soit compensée de l'effet de la température, soit par un organe mécanique destiné à déplacer le centre de gravité mobile, soit par l'application appropriée d'un aimant auxiliaire, ϵ sera indépendant de la température et ρ et δ le seront aussi.

Mais même si l'axe magnétique a été ajusté horizontalement au moment du montage, ϵ ne sera pas nul pendant des perturbations, et, d'ailleurs, sa valeur moyenne sera changée petit à petit par la variation séculaire; par conséquent, les variations de H et de D vont influer sur les observations. Nous donnerons dans le tableau 2 des facteurs de $\triangle H$ et $\triangle D$ respectivement pour des valeurs de Z différentes de 100, 300, 600 γ du champ vertical qui correspond à $\epsilon = 0$.

TABLEAU 2

ΔZ	P_b vers N Facteur de ΔH d'après l'Eq. (2) pour $a_Z =$			P_b vers E Facteur de ΔD d'après l'Eq. (3)					
				pour $H = 10000\gamma$ et $a_Z =$			pour $H = 30000\gamma$ et $a_Z =$		
	$5\gamma/$mm	$10\gamma/$mm	$15\gamma/$mm	$5\gamma/$mm	$10\gamma/$mm	$15\gamma/$mm	$5\gamma/$mm	$10\gamma/$mm	$15\gamma/$mm
γ 100	0.006	0.003	0.002	0.017	0.008	0.006	0.051	0.025	0.017
300	0.017	0.009	0.006	0.051	0.025	0.017	0.152	0.076	0.051
600	0.035	0.017	0.012	0.102	0.051	0.034	0.305	0.152	0.102

On voit du tableau 2 que dans le cas où une balance a été montée de prime abord d'une manière correcte, il faut, si P_b vers N et $a_Z = 5\gamma/$mm, appliquer une correction de $0.017\,\triangle H$ quand la force verticale a changé de 300γ.

Si donc la valeur moyenne de ϵ correspond à 300γ (par ex. comme suite de la variation séculaire) et si l'on ne corrige pas les valeurs de Z obtenues par (1), l'enregistrement de la marche diurne de Z sera modifié (à Godhavn de 2γ) par 0.017 fois la marche diurne de H.

Théorie de la balance magnétique

Décomposons provisoirement la force du champ magnétique terrestre en trois composantes orthogonales; les deux composantes se trouvent dans le plan horizontal, l'une (v) étant l'intersection du plan horizontal par le plan vertical comportant l'axe de rotation de l'aimant,

et l'autre (u) étant perpendiculaire à v. La troisième composante (Z) est dirigée en bas.

Supposons que l'axe magnétique et l'axe de rotation soient per-pendiculaires l'un sur l'autre—ce qui est toujours permis avec l'approxima-tion suffisante.

Dans la figure (1) la droite h-h est horizontale et l-l représente l'axe magnétique qui avec h-h fait l'angle ϵ. Le point O est l'intersection entre le plan vertical hl et l'axe de rotation qui, pour le moment, est supposé horizontal. Le moment de rotation dû à la pesanteur contre-balance donc les deux moments de rotation

$$M (1 + at) Z \cos \epsilon \qquad \text{et} \qquad - M (1 + at) u \sin \epsilon$$

où M est le moment magnétique de l'aimant à 0°C et a est le coefficient de température.

FIG. 1

FIG. 2

FIG. 3
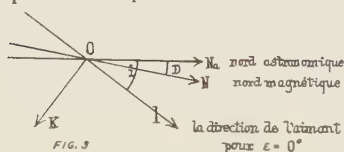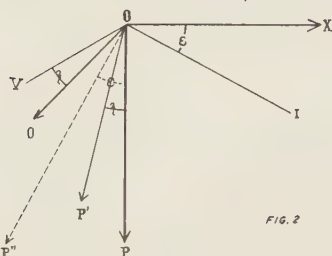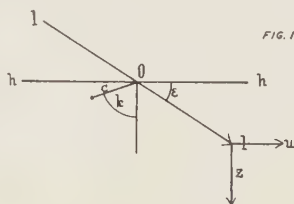
Soient c la longueur de la perpendiculaire sur l'axe de rotation comptée du centre de gravité, et k l'angle que fait cette perpendiculaire avec la verticale; le moment de rotation dû à la pesanteur P est alors

$$Pc \sin k$$

où c peut être considéré constant parce que, dans cette connection, il est permis de considérer l'effet de la température sur c comme compris dans l'effet de la température sur le moment de l'aimant.

L'équilibre est obtenue quand

$$Pc \sin k = M (1 + at) Z \cos \epsilon - M (1 + at) u \sin \epsilon \qquad (4)$$

Nous allons chercher la différentielle totale de ϵ quand Z, u, et t varient.

Cherchons d'abord la dérivée partielle de ϵ par rapport à Z. Puisque $dk = d\epsilon$, on trouve

$$Pc \cos k \; (d\epsilon/dZ) = M \; (1 + at) \cos \epsilon - M \; (1 + at) \; Z \sin \epsilon \; (d\epsilon/dZ)$$
$$- M \; (1 + at) \; u \cos \epsilon \; (d\epsilon/dZ) \tag{5}$$

De (5) on peut tirer que

$$d\epsilon/dZ = M \; (1 + at) \cos \epsilon/[Pc \cos k + M \; (1 + at) \; (Z \sin \epsilon + u \cos \epsilon)]$$

d'où sa réciproque

$$dZ/d\epsilon = [P \; c \cos k/ \; M \; (1 + at) \cos \epsilon] + Z \tan g \; \epsilon + u \tag{6}$$

Il s'ensuit que l'accroissement $\triangle Z$, nécessaire pour faire tourner l'aimant un angle d'une minute, sera

$$\triangle Z = \big\{[Pc \cos k/M \; (1 + at) \cos \epsilon] + Z \tan g \; \epsilon + u\big\} \tan g \; 1' = 1/s \tag{6'}$$

L'angle a été remplacé par sa tang. P étant mesuré en CGS, M en CGS $\times 10^5$, Z et u en CGS $\times 10^{-5}$ (γ), $1/s$ est compté en γ/minute.

$(1/s)$ est la valeur d'échelle de l'aimant. On voit que $(1/s)$ est une fonction de u. En cas de P_b vers N ou vers S, u est égal à $+H$ ou $-H$ respectivement, et par conséquent $1/s$ est $2 \; H$ tang $1'$ plus grand dans le premier cas que dans le second.[1, 2]

Puis, nous cherchons la dérivée partielle de ϵ par rapport à u. De (4) on déduit

$$d\epsilon/du = [- M \; (1 + at) \sin \epsilon]/[Pc \cos k + M \; (1 + at) \; (Z \sin \epsilon + u \cos \epsilon)]$$

Enfin, la dérivée partielle de ϵ par rapport à t est déterminée. On trouve

[1] Voir Communications Magnétiques No. 8, page 16.

[2] $(dZ/d\epsilon)$ étant une fonction de ϵ, nous examinerons la seconde dérivée de Z par rapport à ϵ. On trouve que, si ϵ croît de 0 jusqu'à ϵ, $(dZ/d\epsilon)$ sera augmenté de la fraction ϵ^2 de sa valeur originale. Le tableau 3 contient les valeurs d'échelle pour les diverses valeurs de ϵ. La valeur d'échelle pour $\epsilon = 0$ est prise pour unité.

TABLEAU 3

ϵ	0°	1°	2°	3°	4°
$(1/s)$	1.000	1.0003	1.001	1.003	1.005

Les détails du calcul sont les suivants:

$(d^2Z/d\epsilon^2) = [Pc/M(1+at)] \; [(- \cos \epsilon \sin k + \sin \epsilon \cos k)/\cos^2 \epsilon] + Z/\cos^2 \epsilon + (dZ/d\epsilon) \tan g \; \epsilon$

$(d^2Z/d \epsilon^2) = [-Pc \sin (k - \epsilon) + M \; (1 + at) \; Z + M \; (1 + at) \sin \epsilon \cos \epsilon \; (dZ/d\epsilon)]/M \; (1 + at) \cos^2 \epsilon$

Nous avons avec approximation $Z = Z_o + (dZ/d\epsilon) \; \epsilon$ où Z_o est la valeur de Z pour $\epsilon = 0$ et, d'ailleurs, $M \; Z_o \; (1 + at) = Pc \sin \; (k - \epsilon)$ d'où suit

$(d^2Z/d\epsilon^2) = [M \; (1 + at) \; (dZ/d\epsilon) \; \epsilon + M \; (1 + at) \sin \epsilon \cos \epsilon \; (dZ/d\epsilon)]/M \; (1 + at) \cos^2 \epsilon$

et avec omission des termes d'un ordre supérieur de ϵ

$(d^2Z/d\epsilon^2) = 2\epsilon \; (dZ/d\epsilon)$ ou $[1/(dZ/d\epsilon)] \; [d(dZ/d\epsilon)/d\epsilon] = 2\epsilon$

Nous cherchons l'accroissement de $(dZ/d\epsilon)$ quand ϵ croît de 0 à ϵ

$$\int_0^\epsilon d \frac{dZ}{d\epsilon} \Big/ \frac{dZ}{d\epsilon} = \int_0^\epsilon 2\epsilon \; d\epsilon = \epsilon^2 \quad \text{ou} \quad l \left(\frac{dZ}{d\epsilon}\right)_\epsilon - l \left(\frac{dZ}{d\epsilon}\right)_0 = \epsilon^2$$

d'où

$$\left(\frac{dZ}{d\epsilon}\right)_\epsilon : \left(\frac{dZ}{d\epsilon}\right)_0 = e^{\epsilon^2} = 1 + \epsilon^2$$

$$Pc \cos k \ (\mathrm{d}\epsilon/\mathrm{d}t) \ = \ - \ M \ (1 + at) \ Z \sin \epsilon \ (\mathrm{d}\epsilon/\mathrm{d}t) \ - \ M \ (1 + at)$$
$$u \cos \epsilon \ (\mathrm{d}\epsilon/\mathrm{d}t) \ + \ M \ a \ (Z \cos \epsilon \ - \ u \sin \epsilon)$$

d'où avec omission des termes relativement petits

$$(\mathrm{d}\epsilon/\mathrm{d}t) \ = \ M \ a \ Z/[Pc \cos k \ + \ M \ (1 + at) \ (Z \sin \epsilon + u \cos \epsilon)]$$

De la différentielle totale $\mathrm{d}\epsilon \ = \ (\mathrm{d}\epsilon \ \mathrm{d}Z) \ \mathrm{d}Z \ + \ (\mathrm{d}\epsilon \ \mathrm{d}u) \ \mathrm{d}u \ + \ (\mathrm{d}\epsilon \ \mathrm{d}t) \ \mathrm{d}t$ on trouve

$$\mathrm{d}Z \ = \ [1/(\mathrm{d}\epsilon/\mathrm{d}z)] \ \mathrm{d}\epsilon \ - \ [1/(\mathrm{d}\epsilon/\mathrm{d}Z)] \ (\mathrm{d}\epsilon/\mathrm{d}u) \ \mathrm{d}u \ -[1/(\mathrm{d}\epsilon/\mathrm{d}Z)]$$
$(\mathrm{d}\epsilon/\mathrm{d}t) \ \mathrm{d}t$ et donc
$$\mathrm{d}Z \ = \ [Pc \cos k/M \ (1 + at) \cos \epsilon + Z \ \mathrm{tang} \ \epsilon + u] \ \mathrm{d}\epsilon \ + \ \mathrm{tang} \ \epsilon \ \mathrm{d}u$$
$- \ Z \ a \mathrm{d}t$

Nous allons considérer *le cas général* où l'axe de rotation fait l'angle η avec le plan horizontal.

Dans la figure (2) les trois droites OX, OO, et OP sont orthogonales, OO est l'axe de rotation et OP-OX forment le plan de rotation de l'aimant (le plan du papier). OX est horizontale et forme avec sa perpendiculaire OV le plan horizontal qui fait l'angle η avec le plan OO-OX. La direction de la pesanteur est donc OP' situé dans le plan OO-OP. Ol est l'axe magnétique de l'aimant qui fait l'angle ϵ avec OX. La droite perpendiculaire à l'axe magnétique et à l'axe de rotation est OP'' situé dans le plan OP-OX. Les directions de u, v, et Z sont OX, OV, et OP', et pour déterminer les angles τ_1, τ_2, τ_3, que forment u, v, et Z avec OP'', nous ferons usage des cosines suivantes des angles entre les droites mentionnées et les axes OX, OP, et OO:

Cosines des angles entre	OX	OO	OP
et OP''	$- \sin \epsilon$	0	$\cos \epsilon$
et OX	1	0	0
et OV	0	$\cos \eta$	$- \sin \eta$
et OP'	0	$\sin \eta$	$\cos \eta$

d'où $\cos \tau_1 = \ - \sin \epsilon$, $\cos \tau_2 = \ - \sin \eta \cos \epsilon$, $\cos \tau_3 = \cos \epsilon \cos \eta$.

En cas d'équilibre, on a

$$Pc \sin k \cos \eta \ = \ M \ (1 + at) \ Z \cos \epsilon \cos \eta \ - \ M \ (1 + at) \ u \sin \epsilon$$
$- \ M \ (1 + at) \ v \sin \eta \cos \epsilon$

où $P \cos \eta$ est la projection de la pesanteur sur le plan de rotation. Nous cherchons la différentielle totale de ϵ par rapport à Z, u, v, et t, et par un procédé analogue à celui employé ci-dessus, nous aurons

$$\mathrm{d}Z \ = \ [Pc \cos k/M \ (1 + at) \cos \epsilon \ + \ Z \ \mathrm{tang} \ \epsilon \ + \ u/\cos \eta] \ \mathrm{d}\epsilon$$
$$+ \ (\mathrm{tang} \ \epsilon/\cos \eta) \ \mathrm{d}u \ + \ \mathrm{tang} \ \eta \ \mathrm{d}v \ - \ Za\mathrm{d}t \qquad (7)$$

Désignons par $\mathrm{d}\epsilon$ la valeur $\mathrm{d}\epsilon$ mesurée en minutes, nous aurons alors $\mathrm{d}\epsilon = \mathrm{d}\epsilon \ \mathrm{tang} \ 1'$ où l'angle $1'$ a été remplacé par sa tang.

L'équation (7) peut être écrite

$$\mathrm{d}Z \ = \ (1/s) \ \mathrm{d} \ \underline{\epsilon} \ + \ (\mathrm{tang} \ \epsilon/\cos \eta) \ \mathrm{d}u \ + \ \mathrm{tang} \ \eta \ \mathrm{d} \ v \ - \ Za\mathrm{d}t \qquad (8)$$

ϵ et η étant généralement de petits angles, nous pourrons remplacer tang ϵ et tang η par $\epsilon/3438$ et $\eta/3438$ (ϵ et η mesurés en minutes) et cos η par 1. De (8) on aura donc

$$\mathrm{d}Z = (1/s)\,\mathrm{d}\epsilon + (\epsilon/3438)\,\mathrm{d}u + (\eta/3438)\,\mathrm{d}v - Za\mathrm{d}t \qquad (8')$$

Comme le moment magnétique de l'aimant décroît quand t croît, a est une constante négative.

Le plan du papier (Fig. 3) est horizontal et OK est l'intersection du plan horizontal et un plan vertical comportant l'axe de rotation de l'aimant. Ainsi, OK est la direction de v. Sa perpendiculaire horizontale Ol est la direction de u. i est l'azimut de u compté du nord astronomique vers l'est. D est la déclinaison actuelle, H la valeur de la force magnétique horizontale actuelle. Dans ce cas, on a

$$u = H \cos (i - D)$$
$$v = H \cos (i - D + 90) = - H \sin (i - D)$$

où i est une constante autant que la balance se trouve dans une position fixe. En prenant les différentielles totales par rapport à H et D, on aura

$$\mathrm{d}u = \cos (i - D)\,\mathrm{d}H + \sin (i - D)\,H\mathrm{d}D$$
$$\mathrm{d}v = - \sin (i - D)\,\mathrm{d}H + \cos (i - D)\,H\mathrm{d}D$$

Ici dD est un nombre abstrait. Si dD, mesuré en minutes, est dD, on aura dD = d$D/3438$, et en substituant en (8′) les valeurs de du et dv trouvées ici, on aura

$$\mathrm{d}Z = (1/s)\,\mathrm{d}\epsilon + (\epsilon/3438)\,[\cos (i - D)\,\mathrm{d}H + \sin (i - D)\,H\,(\mathrm{d}D/3438)]$$
$$+ (\eta/3438)\,[- \sin (i - D)\,\mathrm{d}H + \cos (i - D)\,H\,(\mathrm{d}D/3438)]$$
$$- Za\mathrm{d}t$$

ou

$$\mathrm{d}Z = (1/s)\,\mathrm{d}\epsilon + [- (\eta/3438) \sin (i - D) + (\epsilon/3438) \cos (i - D)]\,\mathrm{d}H$$
$$+ [(\eta/3438) \cos (i - D) + (\epsilon/3438) \sin (i - D)]\,(H/3438)\,\mathrm{d}D$$
$$- Za\mathrm{d}t$$

Nous introduisons ρ, δ, et ξ définis par

$$\rho = - (\eta/3438) \sin (i - D) + (\epsilon/3438) \cos (i - D) \qquad (9)$$
$$\delta = [(\eta/3438) \cos (i - D) + (\epsilon/3438) \sin (i - D)]\,(H/3438) \qquad (10)$$
$$\xi = - Za$$

et, par suite, on peut écrire

$$\mathrm{d}Z = (1/s)\,\mathrm{d}\epsilon + \rho\,\mathrm{d}H + \delta\,\mathrm{d}D + \xi\mathrm{d}t \qquad (11)$$

Application

La balance étant employée pour des enregistrements et n'ayant pas de compensation optique de la température, les variations de l'ordonnée ($\triangle Z_{mm}$) sont dues seulement aux variations de ϵ. Si une variation

d'une minute en $\underline{\epsilon}$ correspond à n mm de l'ordonnée, une variation de d$\underline{\epsilon}$ donnera d $(\triangle \bar{Z}_{mm})$ mm déterminé par l'équation

$$d\,\underline{\epsilon} = d\,(\triangle Z_{mm})\ n \tag{12}$$

et

$$dZ = (1/sn)\,d\,(\triangle Z_{mm}) + \rho dH + \delta d\underline{D} + \xi dt$$

d'où par intégration

$$(Z - Z_0) = a_Z\,\triangle Z_{mm} + \rho a_H\,\triangle H_{mm} + \delta a_D\,\triangle D_{mm} + \xi t =$$
$$a_Z\,\triangle Z_{mm} + \rho'\triangle H_{mm} + \delta'\,\triangle D_{mm} + \xi t \tag{13}$$

où $\triangle H_{mm}$ et $\triangle D_{mm}$ sont les ordonnées en mm de l'enregistrement pour D et H. a_H et a_D sont des valeurs d'échelle en γ mm et min mm de H et D respectivement. t est la température actuelle en centigrade, et Z_0 est la valeur de Z pour $\triangle Z_{mm} = \triangle H_{mm} = \triangle D_{mm} = t = 0$. On voit que quand l'axe de rotation et l'axe magnétique d'une balance font des angles avec le plan horizontal, les variations de l'ordonnée $\triangle Z_{mm}$ ne sont pas des vraies expressions pour les variations de la force verticale. Pour obtenir la vraie variation de la force verticale, il faut appliquer une correction par rapport aux variations simultanées de H et de D.

Désignons par $\underline{\epsilon}_0$ et $\underline{\epsilon}$ les petits angles correspondants à $\triangle Z_{mm} = 0$ et $\triangle Z_{mm}$, respectivement; en employant les équations (12) et (13) on peut calculer $\underline{\epsilon}$ par l'équation

$$(\underline{\epsilon} - \underline{\epsilon}_0) = \triangle Z_{mm}/n = [Z - Z_0 - \rho'\triangle H_{mm} - \delta'\triangle D_{mm} - \xi\,t]/n\,a_Z =$$
$$[Z - Z_0 - \rho'\triangle H_{mm} - \delta'\triangle D_{mm} - \xi\,t]\,(1/s) \tag{14}$$

De (14) on voit que $\underline{\epsilon}$ croît quand t décroît.

Supposons que l'on ajoute tout à coup à cette balance non-compensée une compensation optique. Celle-ci ne change pas $\underline{\epsilon}$, mais seulement la direction du rayon enregistrant. La compensation ajoutera à l'équation (13) un nouveau terme $-\xi_1 t$. Ayant appelé la nouvelle valeur de base $(Z_0 + B)$ on peut écrire

$$Z - (Z_0 + B) = a_Z\triangle Z_{mm} + \rho'\triangle H_{mm} + \delta'\triangle D_{mm} + (\xi - \xi_1)\,t \tag{15}$$

En substituant la valeur de Z dans (14), on aura

$$(\underline{\epsilon} - \underline{\epsilon}_0) = (a_Z\,\triangle Z_{mm} + B - \xi_1\,t)/(1/s) \tag{16}$$

En substituant la valeur de (16) dans (9) et (10) et se rappelant que $\rho' = a_H\rho$ et $\delta' = a_D\delta$ nous aurons

$$\rho' = \{ - (\eta/3438)\sin(i - D) + [\epsilon_0/3438 + (a_Z\,\triangle Z_{mm} + B -$$
$$\xi_1 t)/3438\,(1/s)]\cos(i - D)\}\,a_H \tag{17}$$

$$\delta' = \{(\eta/3438)\cos(i - D) + [\epsilon_0/3438 + (a_Z\,\triangle Z_{mm} + B -$$
$$\xi_1 t)/3438\,(1/s)]\sin(i - D)\}\,(H/3438)\,a_D \tag{18}$$

i et η sont des constantes si la balance a une position fixe. En supposant la valeur de base constante, ϵ_0 est aussi constant. Les expressions (17) et (18) montrent que ρ' et δ' ne varient que très peu avec D, car les fac-

teurs sin $(i - D)$ et cos $(i - D)$ sont ou bien de petites quantités ou bien des quantités qui ne varient que relativement peu même quand D varie de quelques degrés. On pourra donc écrire avec approximation

$$\rho' = m' + n' \triangle Z_{mm} + p't \qquad (19)$$

$$\delta' = m_1' + n_1' \triangle Z_{mm} + p_1't \qquad (20)$$

où m', n', p', m_1', n_1', et p_1' sont des constantes et

$$n' = [a_Z/3438 \,(1/s)] \, a_H \cos (i - D) \qquad (21)$$

$$p' = [- \xi_1/3438 \,(1/s)] \, a_H \cos (i - D) \qquad (22)$$

$$n_1' = [a_Z/3438 \,(1/s)] \, (H/3438) \, a_D \sin (i - D) \qquad (23)$$

$$p_1' = [- \xi_1/3438 \,(1/s)] \, (H/3438) \, a_D \sin (i - D) \qquad (24)$$

De (19) et (20) on déduit

$$m' + p't = \rho' - n' \triangle Z_{mm} = \rho_0' \qquad (25)$$

et

$$m_1' + p_1't = \delta' - n_1' \triangle Z_{mm} = \delta_0' \qquad (26)$$

où ρ_0' et δ_0' sont les valeurs de ρ' et δ' pour $\triangle Z_{mm} = 0$. On voit que ρ_0' et δ_0' sont des fonctions linéaires de t et

$$(d \, \rho_0'/d \, t) = p' \qquad (27) \qquad et \qquad (d \, \delta_0'/dt) = p_1' \qquad (28)$$

Exemples numériques

Dans l'équation (15), B est une constante et dans la suite nous désignons $(Z_0 + B)$ par Z_0 seulement. Soit en outre $\beta = (\xi - \xi_1)$ nous aurons pour (15)

$$Z = Z_0 + a_z \triangle Z_{mm} + \rho' \triangle H_{mm} + \delta' \triangle D_{mm} + \beta t \qquad (29)$$

Si, de quelque manière, on a déterminé des valeurs absolues de Z correspondant à quelques valeurs mesurées de $\triangle Z_{mm}$, $\triangle H_{mm}$, et $\triangle D_{mm}$ (t constante, a_Z et β connus) on pourra, à l'aide de ces équations, déterminer les valeurs de ρ' et δ' par le calcul des probabilités. De (25) et (26) on voit que ρ' et δ' sont des fonctions de $\triangle Z_{mm}$ aussi, mais pour ne pas compliquer inutilement les calculs, on peut choisir des enregistrements où les variations de $\triangle Z_{mm}$ sont petites comparées à celles de H et de D, et on peut introduire dans (25) et (26) pour $\triangle Z_{mm}$ la valeur moyenne de $\triangle Z_{mm}$ appelée $\triangle Z_{moy}$. Dans ces conditions, on peut considérer comme des constantes les valeurs

$$\rho' = \rho'_0 + n' \triangle Z_{moy} \quad (30) \qquad et \qquad \delta' = \delta'_0 + n_1' \triangle Z_{moy} \quad (31)$$

Dans la suite, on n'a pas déterminé les valeurs absolues de ρ' et δ' mais des valeurs relatives obtenues en comparant deux balances.

Nous avons comparé deux variomètres pour la force verticale; tous les deux étaient des balances de Godhavn montées à Julianehaab (Groenland) pendant l'Année Polaire. Pour le variomètre sensible, nous avons employé l'équation

$$Z = Z'_0 + a'_Z \triangle Z'_{mm} + \rho' \triangle H'_{mm} + \delta' \triangle D'_{mm} + \beta' t$$

et pour le variomètre peu sensible

2

$$Z = Z''_0 + \alpha''_z \triangle Z''_{mm} + \rho'' \triangle H'_{mm} + \delta'' \triangle D'_{mm} + \beta'' t$$

où nous avons considéré les deux variomètres, étant placés l'un près de l'autre dans une tente isolée, comme ayant la même température dans le cas considéré.

De ces deux équations, on déduit directement

$$\alpha''_z \triangle Z''_{mm} - \alpha'_z \triangle Z'_{mm} + (\beta'' - \beta')\,(t - t_0) = (\rho' - \rho'')\,\triangle H'_{mm} + (\delta' - \delta'')\,\triangle D'_{mm} + Z_0' - Z_0'' - (\beta'' - \beta')\,t_0 \qquad (32)$$

où t_0 est une constante.

Si ϵ', η', ϵ'', et η'' sont zéro on voit des équations (9) et (10) que l'expression à droite dans l'équation (32) se réduit à la constante $Z_0' - Z_0'' - (\beta'' - \beta')\,t_0$.

Pour le 20 septembre 1933 on a mesuré les ordonnées $\triangle Z'_{mm}$, $\triangle Z''_{mm}$ et $t - t_0$ (où $t_0 = 8°.9$) qui sont données dans le tableau 4 avec les T.M.G. correspondants.

TABLEAU 4—*Valeurs du 20 septembre 1933*

T.M.G.	$\Delta Z'_{mm}$	$\Delta Z''_{mm}$	$(t-t_0)$	Σ'	Δ'	$\Delta H'_{mm}$	$\Delta D'_{mm}$	Σ''	Δ''
h m									
3 20	0.9	17.2	0	403	6*	15*	10	401*	2
30	4.7	17.9		406*	3	12*	3	405	−1*
40	4.2	17.9		408	1*	7	6	405*	−2
50	10.8	18.9		409	0*	3	15	405*	−2
59	33.1	22.1		408*	1	−10*	15	402*	1
4 00	37.6	22.9	0	412	−2*	− 8*	19	405	−1*
01	42.0	23.4		408*	1	− 5*	21	402*	1
05	40.1	23.1		408	1*	− 4*	18*	402*	1
10	42.9	23.6		410*	−1	− 8	14*	404*	−1
15	42.6	23.6		410*	−1	−16*	9	403*	0
20	31.8	22.0*		412	−2*	−38*	− 2*	402*	1
25	7.7	18.5*		411*	−2	−41*	−22	403*	0
30	9.1	18.9		415	−5*	−49	−16	405*	−2
35	12.4	19.3*		414	−4*	−50*	−28	404*	−1
40	25.6	21.1		410*	−1	−43	−18*	401*	2
45	44.0	24.0		416	−6*	−50	4	404*	−1
50	27.2	21.3*		411	−1*	−42	−16	402	1*
55	24.2	21.0*		413*	−4	−43	16	403*	0
59	49.0	24.7		415*	−6	−36	4	406	−2*
5 00	44.1	23.9	0	413	−3*	−31*	− 1*	404*	−1
01	38.3	22.9*		410*	−1	−28*	− 3	402*	1
05	33.9	22.2		408	1*	−27	6	400	3*
20	26.0	21.1		409	0*	−22*	− 2*	402	1*
30	8.4	18.5*		409*	0	−27	−11	403	0*
40	19.1	20.0*		407*	2	−17	8*	401	2*
50	14.7	19.6		412	−2*	−14	7	406	−2*
6 00	13.8	19.1*	0	405	4*	− 6*	14*	400	3*
10	− 3.4	16.8		407*	2	− 2*	20	403*	0
20	3.1	17.7		407	2*	2*	15*	403*	0
30	−10.1	15.7		405*	4	− 1	14	402	1*
40	−17.7	14.7*		408*	1	− 4	17	404*	−1
50	−19.2	14.4	0.1	405*	4	1*	18	402*	1
7 35	−27.1	13.2*		405	4*	3*	16	402*	1
40	−25.2	13.6		407	2*	3*	17	404*	−1
45	−25.2	13.6	0.1	407	2*	6	17	404*	−1

*indique "à peu près un demi."

A l'observatoire on a déterminé $a'_z = 3.42 \; \gamma/mm$, $(\beta'' - \beta') = -2.5 \; \gamma/°C$ et $a''_z = 23.6 \; \gamma/mm$. La dernière valeur étant seulement une valeur approximative, nous écrivons $a''_z = 23.6 - \triangle a''_z$ où $\triangle a''_z$ est une correction que nous allons calculer dans la suite.

De (32) on déduit donc

$$23.6 \; \triangle Z''_{mm} - 3.42 \; \triangle Z'_{mm} - 2.5 \; (t - t_0) = \triangle a''_z \; \triangle Z''_{mm} + (\rho' - \rho'') \triangle H'_{mm}$$
$$+ (\delta' - \delta'') \; \triangle D'_{mm} + Z_0' - Z_0'' + 2.5 \; t_0 \qquad (33)$$

Dans la colonne Σ' on trouve les valeurs de $23.6 \triangle Z''_{mm} - 3.42 \triangle Z'_{mm} - 2.5 \; (t - t_0)$ calculées pour les différentes valeurs de $\triangle Z''_{mm}$ et $\triangle Z'_{mm}$. La valeur moyenne de Σ' est 409.5, et les écarts de cette moyenne sont donnés dans la colonne $\triangle'$. On voit que les écarts ont un caractère systématique. Enfin, on a mesuré les ordonnées $\triangle H'_{mm}$ et $\triangle D'_{mm}$; puis, on a établi l'équation

$$\Sigma_1' = 403 = \triangle a''_z \times 17.2 + (\rho' - \rho'') \times 15.5 + (\delta' - \delta'') \times 10 + x \times 1$$

et les 34 équations analogues. De ces équations on a trouvé par le calcul des probabilités
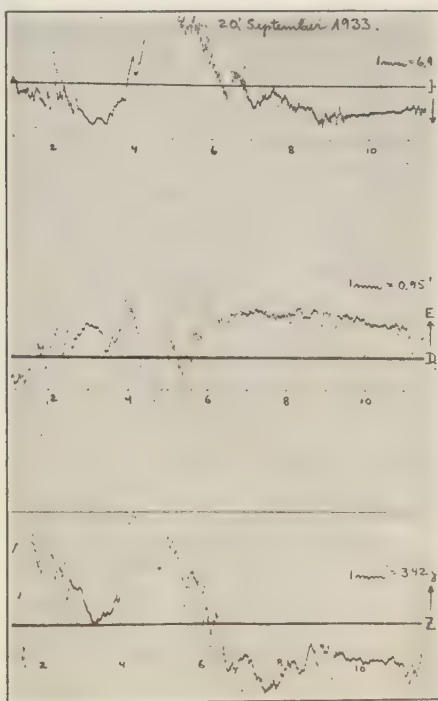

Fig. 4

$$\triangle a''_z = 0.18; (\rho' - \rho'') = -0.14; (\delta' - \delta'') = 0.04; x = 403.5.$$

On a donc de (33)

$$23.6 \triangle Z''_{mm} - 3.42 \triangle Z'_{mm} - 2.5 (t - t_0) - 0.18 \triangle Z''_{mm} + 0.14 \triangle H'_{mm}$$
$$- 0.04 \triangle D'_{mm} = Z'_0 - Z''_0 + 2.5 t_0$$

$Z'_0 - Z''_0 + 2.5 t_0$ est donné dans la colonne nommée Σ''. La colonne $\triangle''$ donne les écarts de la moyenne.

Dans la figure 4 on voit l'enregistrement du variomètre sensible avec les ordonnées employées dans les calculs. On voit que même pour un jour troublé l'erreur moyenne de la différence $(Z'_0 - Z''_0)$ n'est que 1.2γ à peu près. Cette erreur correspond à 1 20 mm de l'ordonnée du variomètre peu sensible.

Pour les jours cités ci-dessous on a déterminé, par des procédés analogues, $(\rho' - \rho'')$ et $(\delta' - \delta'')$ et parfois $\triangle a''_z$.

TABLEAU 5—*Valeurs, 29 octobre 1932—20 septembre 1933*

Date	a z	z − ?	$\delta' - \delta''$	$\Delta Z'_{moy}$	$\Delta Z''_{moy}$	$\Delta Z'_{moy} - \Delta Z''_{moy}$		$\rho' - \rho''$	$\delta' - \delta''$
						$\times 1.82 \times 10^{-3}$	$\times (-0.87 \times 10^{-3}$		
1932-33				mm	mm				
Oct. 29	......	−0.21	0.04	21	10	0.056	−0.027	−0.153	0.013
Nov. 2	......	......	0.15	16	9	....	−0.022	....	0.128
Janv. 19	23.73	−0.23	0.12	12	3	0.027	−0.013	−0.203	0.107
Févr. 2	......	−0.22	....	23	5	0.051	−0.024	−0.169	....
Ma. 7	...	−0.12	0.14	−12	6	−0.011	0.005	−0.131	0.145
Juil. 20	......	−0.02	0.06	−12	9	−0.006	0.003	−0.026	0.063
Sept. 20	23.42	−0.14	0.04	8	12	0.036	−0.017	−0.104	0.023

Dans les colonnes $\triangle Z'_{moy}$ et $\triangle Z''_{moy}$ on trouve les moyennes de $\triangle Z'_{mm}$ et $\triangle Z''_{mm}$ employées dans les calculs. Tandis que $(\rho' - \rho'')$ et $(\delta' - \delta'')$ sont des fonctions de t et de $\triangle Z'_{moy}$ et de $\triangle Z''_{moy}$ (voir 30 et 31), $(\rho'_0 - \rho''_0)$, et $(\delta'_0 - \delta''_0)$ sont seulement des fonctions de t. Les valeurs des colonnes $\rho'_0 - \rho''_0$ et $\delta'_0 - \delta''_0$ sont déduites de $\rho' - \rho''$ et $\delta' - \delta''$, à l'aide des équations (21) et (30) et (23) et (31), eu égard aux constantes des instruments considérés qui sont
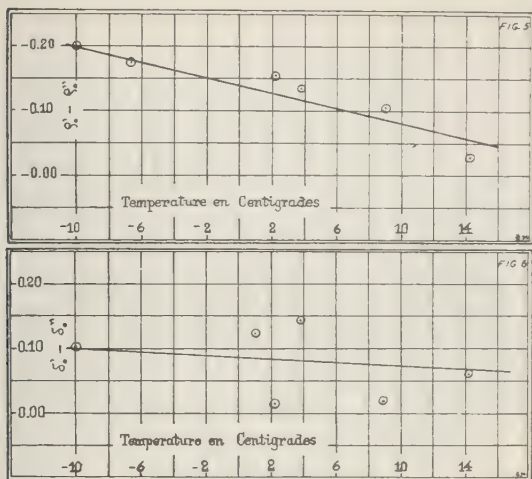
$$(i' - D) = 155°; (i'' - D) = 335°; a'_z (1/s') = a''_z /(1/s'') = 1;$$

$$a'_H = 6.9 \gamma / mm; a'_D = 0.95 \text{ minute} / mm; II = 11500 \gamma.$$

On trouve

$$(\rho'_0 - \rho''_0) = (\rho' - \rho'') + 1.82 \times 10^{-3} (\triangle Z'_{moy} + \triangle Z''_{moy})$$

$$(\delta'_0 - \delta''_0) = (\delta' - \delta'') - 0.87 \times 10^{-3} (\triangle Z'_{moy} + \triangle Z''_{moy})$$

Dans la figure 5 on voit $(\rho'_0 - \rho''_0)$ comme une fonction de t. On en trouve

d $(\rho'_0 - \rho''_0)/dt = 0.0058 = (p' - p'')$ (voir 27)

Comme

$$p' = \left\{ - \xi'_1/[3438 \ (1/s')] \right\} \cos (i' - D) \ a'_H \ \text{et} \ p'' = \\ \left\{ - \xi''_1/[3438 \ (1/s'')] \right\} \cos (i'' - D) \ a'_H \ (\text{voir } 22)$$

et comme on a trouvé des enregistrements en question: $\xi'_1 = 8.5\gamma$/° C et $\xi''_1 = 14.4\gamma$/°C nous aurons

$$(p' - p'') = (- 8.5/3438 \times 3.42) \times (- 0.91) \times 6.9 - (-14.4/3438 \\ \times 23.6) \times 0.91 \times 6.9 = 0.0057$$

Par un procédé analogue on a calculé la valeur—0.00121 pour d $(\delta'_0 - \delta''_0)/dt$ et on a tiré une droite, avec la direction calculée, entre les points sur la figure 6 qui donne $(\delta'_0 - \delta''_0)$ comme une fonction de t.

Pour les deux variomètres considérés, on a donc la formule générale

$$Z'_0 - Z''_0 + (\beta' - \beta'') \ t_0 = 23.6 \ \triangle Z''_{mm} - 3.42 \ \triangle Z'_{mm} - (\beta' - \beta'')(t - t_0) -$$

$$[(\rho'_0 - \rho''_0) - 1.82 \times 10^{-3} \ (\triangle Z'_{mm} + \triangle Z''_{mm})] \ \triangle II'_{mm} - [(\delta'_0 - \delta''_0) +$$

$$0.87 \times 10^{-3} \ (\triangle Z'_{mm} + \triangle Z''_{mm})] \ \triangle D'_{mm}$$

où $(\rho'_0 - \rho''_0)$ et $(\delta'_0 - \delta''_0)$ sont les valeurs prises des figures 5 et 6. Ci-dessous nous donnerons deux exemples où cette formule a été appliquée. Les symboles sont les mêmes que ceux employés plus haut, abstraction faite de t qui est l'ordonnée du T-miroir en mm. Pour $(\beta' - \beta'')$ on a dans ces cas la valeur 2.96 et pour t_0 les valeurs $t_0 = - 2.5$ mm et $t_0 = 0$ mm, respectivement.

Tableau 6—*Valeurs du 19 janvier 1933*

T.M.G.		$\Delta Z'_{mm}$	$\Delta Z''_{mm}$	$(t-t_0)$	Σ'	Δ'	$\Delta H'_{mm}$	$\Delta D'_{mm}$	Σ''	Δ''
h	m									
14	00	15.5	3.0*	0.1	18*	−3*	11	0*	21	−0*
	10	15.9	3.0*		17	−2	11	−2	19*	1
	20	23.8	4.1		15	0	13*	2	18	2*
	30	27.3	4.7		18	−3	14	0*	21	−0*
	40	31.8	5.3		16	−1	16	1	19*	1
	50	34.0	5.6		16	−1	18	5*	19*	1
15	00	40.2	6.5	0.0	16	−1	25	9	21	−0*
	10	34.8	5.8*		19	−4	19*	16	21*	−1 ·
	20	31.0	5.2		17	−2	28	9	22*	−2
	30	31.9	5.2		14	1	33*	16	20	0*
	40	21.8	3.7*		14	1	42·	22	21*	−1
	45	0.8	0.7		14	1	34	27	19	1*
	50	−11.4	−0.9*		17	−2	32*	28*	21*	−1
	55	−16.9	−1.7*		17	−2	36	32	22	−1*
16	00	−11.0	−0.9	−0.1	17	−2	38	33	22	−1*
	05	− 5.2	−0.1		16	−1	42*	36*	22	−1*
	10	− 1.2	0.3		12	3	43	26	19	1*
	15	0.2	0.7		16*	−1*	43*	20	24*	−4
	20	5.0	1.2		11*	3*	46*	21*	20	0*
	25	19.7	3.2*		9*	5*	49	20	18*	2
	30	28.2	4.6*		13*	1*	44	35	20	0*
	40	28.6	4.7		13	2	42	26*	20·	0*
	50	29.0	4.7*		13	2	40*	21*	20	0*
17	00	30.0	4.8*	0.0	12	3	36	19	18	2*
	05	24.0	4.0*	0.0	13*	1*	33	15*	19*	1
	50	26.3	4.3*	0.1	12	3	27*	6	17*	3
19	00	25.2	4.2	0.2	12*	2*	30	10	18*	2
	15	21.0	3.8	0.3	17	−2	25	9*	21*	−1
20	00	16.0	3.1	0.3	17*	−2*	21	10	21*	−1
21	00	22.2	4.0	0.2	18	−3	18	6*	21*	−1
23	00	5.7	1.6	0.1	17*	−2*	13	4	20	0*
	10	0.7	1.0	0.1	20*	−5*	4	1*	21	−0*

*indique "à peu près un demi."

Tableau 7—*Valeurs, 1ᵉʳ janvier—23 avril 1933*

Date	T.M.G.		$\Delta Z'_{mm}$	$\Delta Z''_{mm}$	$(t-t_0)$	Σ'	$\Delta H'_{mm}$	$\Delta D'_{mm}$	Σ''
1933	h	m							
Janv. 1	21	20	− 0.3	0.6*	0.0	16	35	22*	20.5
6	06	15	2.0	1.4	0.7	24	− 3	18	22
10	18	℃	21.0	4.1*	2.0	20	14*	4	23
15	21	45	7.7	2.7	2.6	29*	−26	− 3	24.5
19	22	00	18.3	3.4	− 2.1	24	15*	4	27
25	00	00	−11.8	−1.3	− 3.1	19	11	1	21.5
30	22	0C	− 8.5	−0.0*	3.9*	16	20	17	18
Févr. 4	18	00	26.2	5.1	5.1	16	27*	4	22
9	07	00	26.5	5.7	8.3	19*	− 5*	13*	19
13	18	00	13.3	4.3*	13.9	16	12	9	18
18	06	00	10.0	4.0	14.2	18	13	7	19.5
22	08	25	− 2.6	2.8*	16.1	28*	−23	25*	22.5
28	21	00	8.2	5.0*	22.3	25	12	6	26.5
Mars 5	21	00	11.2	5.2	21.3	21	15	9*	23
10	21	30	− 2.1	3.1	17.7	28	22	14	30.5
15	22	00	10.8	6.0	23.7	34	16	12	34.5
23	21	45	−20.8	1.0*	20.4	35*	− 7	−22*	36
23	21	50	−13.8	1.8	20.4	29	− 2	−37	31.5
25	22	15	− 8.1	3.9	26.2	41	21*	11	43 5
31	22	00	4.6	6.0	28.4	41*	17*	13	43
Avril 10	21	00	4.6	5.7	26.6	40	14	9	41.5
23	10	30	2.4	5.4	25.6	43	10*	18	43

*indique "à peu près un demi."

Copenhague, le 7 août 1934

EARTH-CURRENT MEASUREMENTS AT THE COLLEGE-FAIRBANKS POLAR-YEAR STATION

BY W. J. ROONEY AND K. L. SHERMAN

Abstract—Continuous registration of earth-current potentials was begun in September 1932 at the College-Fairbanks (Alaska) Polar-Year Station and continued until the end of March 1934. The potentials measured were those between two pairs of electrodes, one pair 1.28 km apart on a due south-north line and the other 1.21 km apart on a due west-east line. The electrodes were grids of lead buried at a depth of about one meter. The measuring apparatus consisted of two Leeds and Northrup type-R galvanometers and a la Cour photographic recorder. The current-sensitivity of the galvanometers, about 1×10^{-10} ampere per millimeter deflection on the drum, permitted the use of resistances of 2.0 megohms in series with them, so that the total circuit-resistances were not markedly affected by variations in the contact-resistances of the electrodes. The total external resistance of each circuit was less than 300 ohms during the summer and, although it increased considerably during the winter months due to increased contact-resistances at the electrodes as the soil about them froze, it never reached as much as one per cent of the total circuit-resistance in the case of the west-east line or as much as three per cent in the case of the south-north line.

The records for a full year, from October 1, 1932, to September 30, 1933, have been reduced. The most striking feature of the records is the comparatively great short-period fluctuations, often oscillatory in character, which are found to occur almost exclusively at night, and the contrasting smoothness of the traces during the daylight hours. The amplitude of these short-period oscillations frequently reaches one volt per kilometer or more. Corresponding in time to these short sharp pulsations at College disturbances less conspicuous in intensity and abruptness are invariably found in the records from Tucson (Arizona), and in the case of strong isolated disturbances the effect is noticeable also in the records from Huancayo (Peru). They are not at all local in character, but rather due to an intensification of widespread electrical disturbances.

The mean diurnal-variation curve for the northward component shows a fairly smooth double oscillation in potential gradient with maxima at about 5^h and 16^h local time, and minima just before noon and midnight. Its mean diurnal range is about 14 mv/km if all days are included and about 11 mv/km on calm days only. The same type of diurnal variation persists throughout the year with a considerably smaller range, 7 to 9 mv/km during the winter, and a corresponding increase, 17 to 22 mv/km, in the summer.

The diurnal-variation curve for the eastward component during the winter is essentially the same as the northward curve except for a reversal in sign and a somewhat smaller amplitude. The diurnal-variation curve obtained during the summer tends more toward a single-period curve, the mean curve for the year being intermediate between the two. There is some evidence that the records of the eastward component were affected somewhat by contact-potentials at the electrodes during the summer.

A comparison of the earth-current and auroral records at College shows considerable agreement between aurorae and disturbances in the earth-current records.

Continuous registration of earth-current potentials at the College-Fairbanks Polar-Year Observatory was begun late in September 1932 and continued until the end of March 1934. The College-Fairbanks Station, established and operated jointly by the United States Coast and Geodetic Survey and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, was located on the grounds of the Alaska Agricultural College and School of Mines about three miles northwest of the city of Fairbanks, in latitude 64°.9 north and longitude 147°.8 west. Records for the one year period from October 1, 1932 to September 30, 1933, which includes eleven of the thirteen months designated as the Jubilee International Polar Year, 1932-33, have been evaluated. The chief features of the measurements and results are briefly described herein.

Layout and equipment— Four electrodes designated as S, N, E, and W were installed—S and N, on a due south-north line and the other pair on a due west-east line. The length of the south-north line was 1.28 km and that of the west-east line 1.21 km. The lines joining the two pairs of

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electrodes crossed each other at a point about 0.38 km east of the west electrode and 0.43 km north of the south electrode, the system so forming a rough cross with arms of unequal length. The site was flat as a whole, the differences in the elevations of electrodes S, N, and E being quite negligible while W was at an elevation less than 15 meters greater. The area bounded by the electrodes consisted mostly of meadow land and "tundra" typical of that portion of Alaska with a narrow spit of firm ground sloping down into it from the west near electrode W. The surface-soil was a firm clay at electrode W and semi-fluid muck at the other electrodes. The entire region about the installation is characterized by a permanently frozen sub-soil from a depth of two or three feet to 150 feet or more, usually right down to bedrock.

Each electrode consisted of a cross-shaped grid of pure lead-wire set horizontally in the ground at a depth of some two and one half feet and making contact with the earth over an effective area of about twenty-five square feet. "Tyrex" cable with heavy rubber insulation was used to connect the electrodes to the lines. Overhead conductors of No. 14 (Browne and Sharp gage) copper wire mounted on poles and insulators led from the "Tyrex" connectors to the recording instruments.

The potentials were recorded photographically on a la Cour recorder by means of two D'Arsonval type galvanometers (Leeds and Northrup type R) with current-sensitivities of 10^{-10} ampere per millimeter deflection as used and critical damping resistance of 21000 ohms. The essentials of the recording circuit, which has been described in detail previously,[1] are shown in Figure 1. Each galvanometer, shunted by its
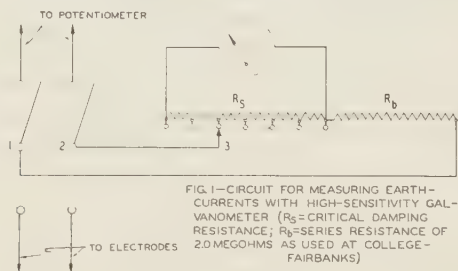

FIG. I—CIRCUIT FOR MEASURING EARTH-CURRENTS WITH HIGH-SENSITIVITY GAL-VANOMETER (R_S=CRITICAL DAMPING RESISTANCE; R_b=SERIES RESISTANCE OF 2.0 MEGOHMS AS USED AT COLLEGE-FAIRBANKS)

critical damping resistance, was connected in series with a constant resistance, R_b, so large compared to the contact-resistances at the electrodes and to the shunt-resistance that the total resistance of the circuit changed but little with variation of the electrode-resistances or with changes in the position of the movable line-terminal shown at point 3. The advantages of having a large constant resistance in the circuit are: (a) Variations in the electrode-resistances do not affect the recorded values unless the variations are abnormally great; (b) consequently the electrode-resistances need not be known with high accuracy; (c) direct calibration by substituting known electromotive forces for the unknown potentials is made possible; and (d) the scale-value is practically constant.

Operation and control.—The potentials recorded were for the most

[1] O. H. Gish, Procès-Verbaux, Comm. Année Polaire 1932-1933, Innsbruck, 1931, Organisation Mét. Internat., No. 10, App. H, 177-182 (1932).

part those between the electrode pairs *S-N* and *W-E*, respectively, thus measuring the northward and eastward components of earth-current flow directly. Occasionally the line connections were shifted for ten-day periods and the electrodes used as a three-point system with records obtained from such combinations as *S-N* and *S-W*. This afforded a means of checking on the performance of the electrodes since the general direction of current-flow, the diurnal variation in gradient, etc., as determined from the two sets of records would appear to be different if extraneous potentials from one or more of the electrodes were having an appreciable effect on the results. Time and base-line records were obtained by opening the recording circuits by clock-controlled relays for two minutes at the beginning of each hour and permitting the deflections to fall to zero. Daily calibrations were made, known potentials covering the range of deflections observed during recording being applied from a calibrating unit made up of dry cells, fixed and variable resistances, and a millivoltmeter. The contact-resistances of the electrodes were measured several times during the year to follow the seasonal changes in this factor.

Factors affecting the accuracy of the records—One of the major difficulties expected in measuring earth-currents in a polar region was that of obtaining good and uniform electrical contact with the earth. Particular attention was paid to the electrodes for this reason. The electrode-resistances were determined by bridge-measurements eight times during the year with results as shown in Table 1.

TABLE 1—*Contact-resistance of electrodes of College-Fairbanks earth-current measuring system*

Elec-trode	Date of determination							
	Sep. 9, 1932	Dec. 20, 1932	Mar. 31, 1933	Apr. 22, 1933	Apr. 30, 1933	May 22, 1933	June 6, 1933	Aug. 2, 1933
	ohms	*ohms*	*ohms*	*ohms*	*ohms*	*ohms*	*ohms*	*ohms*
N	25	71	440	143	90	75	40	15
S	100	2600	54000	7200	975	980	435	144
E	215	1220	16300	5960	2710	1330	1020	260
W	40	77	90	121	87	72	55	47

In view of the fact that the temperature at the Station remained below 0° C from the latter part of October until well into April and ranged from −20° to −30° C for three months or more, these results are quite satisfactory. It will be noted that the sum of the contact-resistances of electrodes *E·* and *W* never became as great as one per cent of the constant series-resistance (2 megohms) used in the circuit. The maximum resistance reached by any electrode, that of *S* in March, was less than three per cent of the series-resistance and exceeded the limit of one per cent aimed at only for a comparatively short time. Assuming that the changes in resistance from December 20 to March 31 and from March 31 to April 22 were linear the mean values recorded for the northward component during January, February, and March were corrected by

3

increasing them by 0.75, 1.5, and 2.3 per cent, respectively, to allow for the drop at the south electrode. Since in general only two significant figures have been used in compiling the data these corrections are almost imperceptible even in the March records and their effect is negligible as far as the seasonal and annual means are concerned.

The galvanometers were found to be rather sensitive to changes in temperature and, although the temperature in the atmospheric-electric building was rather closely controlled, the hourly zero-records show considerable shift at times, particularly when the recorder-compart-ment was occupied by the observers for calibration or adjustment. From Figure 1 it is apparent that thermo-electric effects at the taps or galvanometer-terminals could cause a current to circulate through the galvanometer and shunt. Since allowance was made for the shifts in base-line when the traces were scaled it is unlikely that errors of more than a few per cent could creep into the records from this source.

Toward the end of the year a ground on the direct-current power-system of the College near the south electrode was found to affect the records for short intervals at times. The deflections from this source were so large and characteristic as to be readily recognized and the records for those periods were discarded. The possibility that less severe and con-sequently unnoticed grounds might have affected the records at other times is very slight since there is absolutely no difference in the records obtained while the power-plant was in operation and when it was shut down.

Comparisons of the records obtained from the three-point and four-point electrode-combinations made at intervals during the winter indi-cate that the electrode-performance was quite satisfactory during that time. There is no evidence that extraneous effects were entering from variations in the electrochemical potentials at the electrodes. Un-fortunately no three-point recording was done during the last four months and, as will be discussed later, there is some evidence suggesting that the records of the eastward component may have been marred to some extent by electrode-effects during the summer months.

On the whole it is believed that, with the exception just referred to, the records of diurnal variation and of short-period fluctuations are good to a few per cent, certainly to better than ten per cent. Hence the records should suffice to establish the general characteristics of earth-current flow in the region in comparison with those observed at other stations and permit valid comparisons with the magnetic elements and allied phenomena.

Results

General—The most striking feature of the records is the large, rapid, and frequently oscillatory deflections found chiefly during the night hours. At stations in lower latitudes the amplitudes of the short-period disturbances have generally been found to be of the same order of magni-tude as that of the mean diurnal variation. It is only during exceptional disturbances that they become as much as twenty or thirty times as great. In the College-Fairbanks records, on the other hand, the short-period disturbances are so predominant that the diurnal variation is almost imperceptible unless the sensitivity of the recording apparatus is increased to a point where much of the record is lost during even minor disturbances, due to the rapid motion of the recording light-spots. The extreme values

recorded during a single hour frequently exceed the range of diurnal variation by factors between 50 and 150 and in dozens of instances changes in potential a hundred or more times as great as the diurnal variation are found to occur in ten or fifteen minutes. Comparison with the records obtained at the Tucson (Arizona) Observatory shows that the ratio between maximum hourly range and mean diurnal variation is more than five times as great at the Alaskan station. This comparison further shows that these short-period disturbances are not by any means a local phenomenon but rather an intensification of widespread electrical disturbances. Short, sharp pulses of current at College-
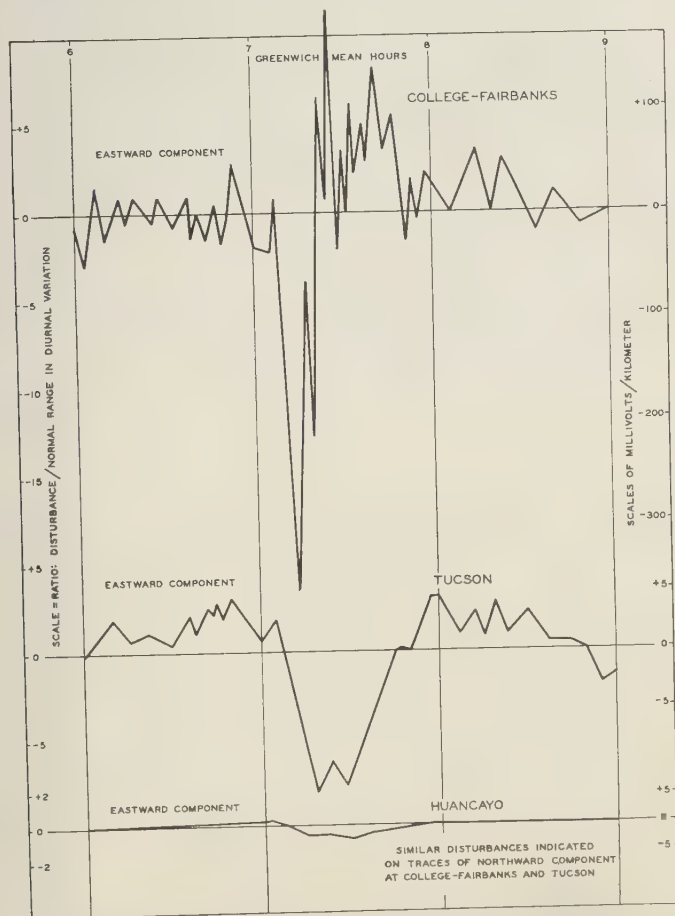
EARTH-CURRENT DISTURBANCES AT COLLEGE-FAIRBANKS, TUCSON, AND HUANCAYO, ACCOMPANYING ISOLATED AURORAL DISPLAY AT COLLEGE-FAIRBANKS, ALASKA, 7 TO 8 GREENWICH MEAN HOURS, DECEMBER 31, 1932

FIG. 2

Fairbanks are invariably accompanied at Tucson by disturbances which are usually less conspicuous in intensity and abruptness so that corresponding in time to the sharp peaks in the polar records there will be found smoother bays in the records at Tucson. By analogy the sharp crash of thunder heard by one close to the stroke and the drawn-out rumble heard at a distance from it describe the two records about as well as anything. Sometimes similar bays appear in the records from both stations as though the focus of disturbance were about the same distance from each but the general tendency is for the College records to show the sharper effect. Pursuing the analogy further it was found, at least in the case of the most pronounced isolated disturbances of this character, that the reverberations or ripples of disturbance extend as far as Huancayo (Peru) where smaller and more rounded bays appear in the records at the same time. A typical case of isolated short-period disturbance is shown in Figure 2. This disturbance occurred on a moderately disturbed day with electrical character-number about 1.2. Sections of the College-Fairbanks, Tucson, and Huancayo records are given in the Figure: the ordinates are on the same scale for the three records on the basis of the ratio of the deflections to the mean range of diurnal variation at the station in question. The scale of ordinates in millivolts per kilometer is also shown to the right of the Figure. It is worthy of note that the most

TABLE 2—*Diurnal variation northward earth-current gradient in millivolts per kilometer, College-Fairbanks Polar-Year Station, for all days recorded October 1932 to September 1933*

(Tabular values are average departures from mean of day of 60-minute means centering on the half-hour, a positive sign indicating current flowing northward is greater than mean of day.)

150° west M.M.T. hour	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Ann-ual	Win-ter*	S
0– 1	−12.6	−3.8	− 5.6	−4.1	−5.7	+0.5	− 6.9	+ 2.0	− 3.5	+ 3.4	− 0.7	−7.9	−3.7	−5.2	−
1– 2	+ 1.6	−1.6	− 5.5	+0.9	−0.9	+1.2	+ 6.4	+ 2.3	− 1.8	− 8.1	− 1.7	+6.5	−0.1	−0.7	+
2– 3	− 3.4	−6.8	− 0.9	−3.9	+2.5	−2.5	+ 2.5	+ 4.4	+ 6.1	− 2.6	− 4.2	−3.3	−1.0	−2.5	+
3– 4	+11.4	+6.0	− 2.6	−1.5	+11.4	+7.3	+ 6.6	− 6.4	+ 2.2	+14.2	+ 7.2	+17.4	+6.1	+5.3	+
4– 5	− 0.1	+5.3	+10.0	+1.2	−3.0	+2.7	+12.3	+12.7	+10.8	+13.4	+ 9.4	+6.6	+6.8	+2.7	+
5– 6	+ 5.6	+2.2	+ 6.0	0.0	+5.7	0.0	+ 7.0	+ 5.3	+ 8.5	+ 8.6	+16.0	+2.1	+5.6	+3.2	+
6– 7	+ 3.5	+0.7	+ 4.4	+6.5	+5.2	+9.2	+ 4.3	+ 2.9	+13.4	+ 7.2	+10.2	+2.3	+5.8	+4.9	+
7– 8	+ 1.2	+0.5	− 0.7	−2.1	−3.8	+6.5	+ 0.2	− 5.1	+ 4.2	+ 1.2	− 1.2	−2.4	−0.1	+0.3	−
8– 9	+ 0.8	−0.5	0.8	+0.4	−4.6	−2.4	− 7.0	− 9.6	− 5.5	− 6.2	− 9.2	−5.0	−4.2	−1.2	−
9–10	− 3.5	−0.6	− 4.4	−5.6	−1.6	−4.3	−13.3	− 8.1	− 8.1	−12.8	−10.3	−8.1	−6.7	−3.3	−
10–11	− 1.8	−2.6	− 6.8	−2.6	−1.1	−6.3	− 9.6	−12.5	−12.9	−13.5	− 9.2	−7.9	−7.2	−3.5	−
11–12	− 1.7	−3.1	− 3.5	−2.2	−5.6	−7.5	− 8.8	− 9.3	−12.1	−13.3	− 8.3	−7.2	−6.9	−3.9	−
12–13	0.0	+2.0	+ 1.4	−0.5	−1.8	−3.8	− 1.6	− 0.5	− 6.3	− 5.8	− 1.5	−2.4	−1.7	−0.4	−
13–14	+ 2.1	+0.6	+ 1.1	+2.7	+0.3	−2.4	− 2.6	− 1.1	− 3.0	− 3.7	+ 1.0	0.0	−0.4	+0.8	−
14–15	+ 5.3	+3.1	+ 2.1	+5.4	+2.6	−1.0	+ 6.0	+ 7.9	+ 1.5	+ 0.5	+ 2.2	+2.9	+3.2	+2.9	+
15–16	+ 7.7	+2.5	+ 4.4	+5.6	+3.0	+2.8	+ 5.5	+ 7.5	+ 3.6	+ 2.2	+ 3.4	+1.3	+4.1	+4.3	+
16–17	+ 3.9	+2.1	+ 4.5	+2.4	−1.5	+0.9	+ 6.1	+ 9.5	+ 7.2	+ 5.4	+ 4.2	+2.2	+3.9	+2.0	+
17–18	+ 2.9	+0.8	+ 3.2	+3.3	+3.6	−2.9	− 1.6	+ 5.7	+ 4.0	+ 5.0	− 1.6	+3.6	+2.2	+1.8	+
18–19	− 0.2	+2.4	+ 2.3	+3.4	+0.2	+5.8	+ 6.6	+ 8.4	+ 4.2	+ 5.6	+ 2.5	+2.0	+3.6	+2.3	+
19–20	+ 4.7	+6.8	+ 1.2	+2.6	+3.3	+5.2	+ 2.0	+ 5.0	+ 2.7	+ 2.6	+ 3.3	+2.1	+3.0	+3.0	+
20–21	− 2.9	+3.0	+ 1.8	+0.3	+0.3	+2.3	+ 4.3	− 1.2	+ 1.3	+ 3.8	− 0.7	+6.0	+1.5	+0.8	+
21–22	− 7.0	−1.9	− 0.7	−1.0	−1.7	−0.1	− 3.2	− 3.9	− 2.8	− 2.0	− 0.3	−7.4	−2.7	−2.1	−
22–23	− 7.5	−5.3	− 5.6	−2.3	−2.1	−4.5	−10.8	− 7.3	−13.0	− 3.0	− 3.8	−1.0	−5.5	−4.6	−
23–24	−10.3	−5.5	− 5.4	−8.9	−4.5	−6.6	− 4.4	− 8.6	− 0.7	− 2.1	− 6.9	−2.4	−5.5	−6.9	−
No. days recorded	27	26	26	28	23	20	29	30	27	29	29	24	318	150	

*October 1932 to March 1933.   †April 1933 to September 1933.

TABLE 3—*Diurnal variation northward earth-current gradient in millivolts per kilometer, College-Fairbanks Polar-Year Station, for ten calm days per month recorded October 1932 to September 1933*

(Tabular values are average departures from mean of day of 60-minute means centering on the half-hour, a positive sign indicating current flowing northward is greater than mean of day.)

West M.T. hrs	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Means Annual	Means Winter*	Means Summer†
1	−2.7	+0.3	−3.6	+0.7	−6.1	+5.7	+3.3	−0.6	+1.5	+1.1	+3.8	+0.2	0.0	−1.0	+1.0
2	−2.5	0.0	+0.3	+3.3	+1.0	+5.4	+0.5	+1.7	−4.1	−0.9	−3.4	+2.1	+0.3	+1.2	−0.7
3	+2.9	+0.2	+3.7	−2.6	+0.4	−5.8	−4.4	−0.6	0.0	+4.1	+3.7	+0.9	+0.2	−0.2	+0.6
4	−4.0	+1.7	+1.8	+7.4	+2.0	+5.5	−1.0	−4.3	+7.6	+5.2	+3.2	+2.4	+2.3	+2.4	+2.2
5	−1.9	+1.0	−0.2	+3.3	+0.2	−1.0	+4.1	+1.7	+10.6	+3.0	+4.4	−2.2	+1.9	+0.2	+3.6
6	−7.2	+0.5	−0.2	+0.8	+0.4	+9.4	+4.3	+1.5	+6.4	+5.5	+4.8	+1.1	+2.3	+0.6	+3.9
7	+4.4	−2.9	0.0	+1.2	+2.7	+9.2	+0.5	+0.7	+8.1	+5.5	+1.9	−2.2	+2.4	+2.4	+2.4
8	+2.4	−3.3	−2.9	−2.1	+0.4	+0.1	−6.2	−5.8	+1.5	+0.9	−2.7	−5.7	−2.0	−0.9	−3.0
9	−2.7	−0.5	−2.6	−1.8	−0.6	−4.2	−2.4	−7.6	−7.3	−5.2	−7.7	−5.2	−4.0	−2.1	−5.9
10	−3.8	0.0	−5.0	−2.4	−2.3	−4.4	−6.6	−9.0	−12.3	−10.6	−12.2	−4.4	−6.1	−3.0	−9.2
11	−3.1	−1.5	−2.6	−3.8	−2.0	−6.6	−6.9	−10.8	−13.9	−13.1	−10.0	−4.7	−6.6	−3.3	−9.9
12	−3.3	−4.2	−1.3	−4.8	−2.9	−6.2	−11.8	−9.0	−14.9	−11.8	−8.5	−6.1	−7.1	−3.8	−10.4
13	−0.6	+2.4	+1.1	−2.0	−3.3	−5.9	−3.3	−1.5	−8.4	−6.5	−2.1	−3.8	−2.8	−1.4	−4.3
14	+1.3	+1.5	+1.6	+2.8	−1.3	−3.1	−4.0	+0.8	−4.0	−2.9	+0.8	+0.2	−0.5	+0.5	−1.5
15	+6.0	+4.0	+2.8	+5.4	+1.0	0.0	+1.8	+8.5	+0.6	+2.1	+4.4	+4.2	+3.4	+3.2	+3.6
16	+6.8	+1.8	+3.5	+2.0	−0.4	−1.1	+6.6	+6.1	+6.2	+2.6	+1.8	+2.2	+3.2	+2.1	+4.3
17	+4.6	+3.5	+4.5	+2.1	+3.9	0.0	+4.8	+10.2	+8.4	+2.7	+3.3	+2.8	+4.2	+3.1	+5.4
18	+1.6	+0.1	+1.7	+1.3	−0.3	−3.3	+2.4	+5.5	+5.4	+3.7	+2.0	+3.4	+4.2	+0.2	+3.8
19	+1.6	−0.1	+1.2	−0.1	+3.2	+2.1	+6.7	+10.6	+7.7	+8.3	+3.3	+2.8	+3.9	+1.3	+6.6
20	+8.5	−0.5	+0.8	+2.3	+2.1	+0.3	+9.3	+5.9	+3.1	+3.8	+1.9	+2.8	+3.4	+2.3	+4.5
21	−0.1	−0.1	−0.5	+1.3	+2.6	+1.5	+4.4	+4.5	+1.1	+2.7	+3.3	+3.9	+2.0	+0.8	+3.3
22	−3.9	+0.4	+0.6	−0.1	+0.9	+0.9	+3.3	−0.4	+0.6	−0.2	+0.7	+0.7	+0.2	−0.3	+0.8
23	−1.9	−1.2	−1.2	−1.5	−1.1	−5.4	−4.3	−2.4	−2.9	0.0	+1.3	+1.0	−1.6	−2.0	+1.2
24	−2.6	−2.2	−3.5	−12.5	−0.5	+7.1	−1.3	−5.6	+2.0	0.0	+2.2	+2.4	−1.2	−2.4	+0.1

*October 1932 to March 1933.   †April 1933 to September 1933.

striking individual auroral display of the winter, at least the display which is described at greatest length and detail in the log of the auroral station conducted by Professor V. R. Fuller at College, occurred exactly at the time of this disturbance.

Diurnal variation—It has been pointed out elsewhere[2], [3], [4] that the absolute or mean values of potential recorded on earthed lines represent chiefly electrochemical effects at the electrodes. Nowhere in the data collected here or elsewhere is there evidence of the existence of a so-called constant part of earth-current flow. Hence only the variations in the recorded potentials are of interest. The variations most readily susceptible to study and analysis are the regular daily fluctuations in the mean hourly values. This diurnal variation for the northward component is shown in Table 2 for all days on which complete and satisfactory records were obtained and in Table 3 for the ten least-disturbed days per month. The mean variations for the year and for the winter and summer half-year periods are also given in the Tables. Similar data for the eastward component are found in Tables 4 and 5. In Table 6 are given the constants for the harmonic series $\Sigma c_n \sin(n\theta + \phi n)$ as determined for the mean annual and semi-annual diurnal-variation data. Although the hourly means are centered on the half-hour, the phase-angles shown have

[2] O. H. Gish and W. J. Rooney, Terr. Mag., **33**, 79 (1928)-90.

[3] O. H. Gish and W. J. Rooney, Terr. Mag., **35**, 213-224 (1930).

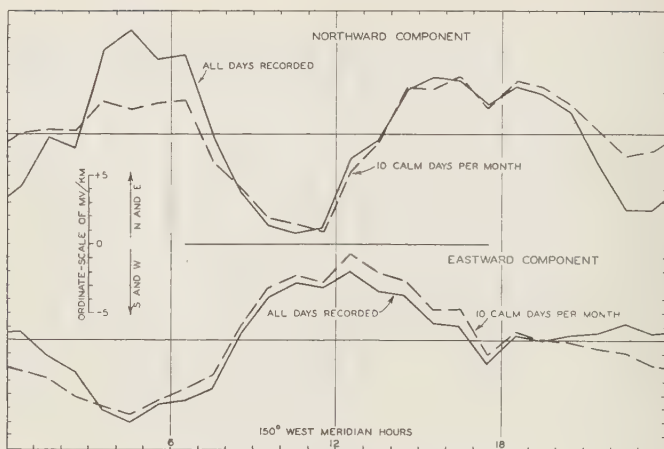[4] W. J. Rooney, Terr. Mag., **37**, 363-374 (1932).

FIG. 3—MEAN DIURNAL VARIATION NORTHWARD AND EASTWARD COMPONENTS OF EARTH-CURRENTS,
AVERAGES ALL DAYS AND TEN CALM DAYS PER MONTH, OCTOBER 1932 TO SEPTEMBER 1933,
COLLEGE-FAIRBANKS POLAR-YEAR STATION

been increased by $7.5n$ degrees so that $\theta = 0°$ in the table corresponds to local midnight.

Mean annual curves of diurnal variation are shown in Figure 3 for all days and for the ten least-disturbed days per month. The all-days mean for the northward component includes 318 days and that for the
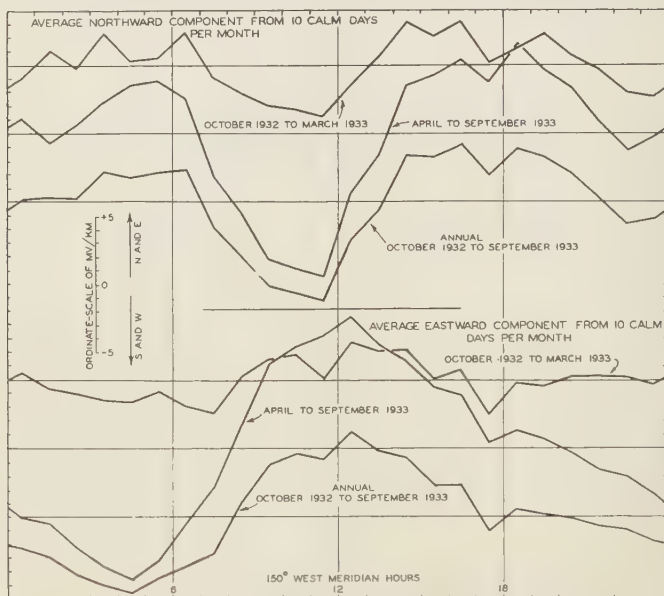

FIG. 4—DIURNAL VARIATION NORTHWARD AND EASTWARD COMPONENTS OF EARTH-CURRENTS,
AVERAGES OF TEN CALM DAYS PER MONTH, WINTER, OCTOBER 1932 TO MARCH 1933, AND SUMMER,
APRIL TO SEPTEMBER 1933, COLLEGE-FAIRBANKS POLAR-YEAR STATION

TABLE 4—*Diurnal variation eastward earth-current gradient in millivolts per kilometer, College-Fairbanks Polar-Year Station, for all days recorded October 1932 to September 1933*

(Tabular values are average departures from mean of day of 60-minute means centering on the half-hour, a positive sign indicating current flowing eastward is greater than mean of day.)

west .T. rs	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Means		
													Annual	Winter*	Summer†
1	+ 5.0	+5.1	+ 2.6	−0.8	+2.6	+3.1	+ 0.1	− 1.7	− 6.4	− 3.7	− 1.6	+2 7	+0.6	+2.9	1.8
2	− 2.0	+2.0	+ 3.6	−0.7	+3.6	+1.8	− 5.4	− 3.4	− 7.1	− 5.2	− 1.5	−1.0	−1.3	+1.4	3.9
3	0.0	+4.5	+ 0.5	+1.3	+1.2	+2.8	− 4.9	− 6.2	−13.6	− 8.6	− 3.2	−1.6	−2.3	+1.7	− 6.3
4	− 3.8	−2.2	+ 2.1	−1.6	−3.9	−3.2	− 9.1	− 2.8	−12.7	− 9.1	− 7.6	−7.8	−5.1	−2.1	− 8.2
5	− 3.2	−3.1	− 3.5	+0.6	+0.3	−1.6	−10.7	−11.6	−15.5	− 8.5	−10.1	−5.2	−6.0	−1.7	−10.3
6	− 5.6	−2.2	− 2.2	+1.2	−2.0	+2.0	− 6.2	− 6.4	−13.3	− 8.4	−11.9	−3.6	−4.9	−1.5	− 8.3
7	− 5.3	−0.6	− 1.6	−2.9	−2.8	−5.9	− 0.6	− 4.4	−11.9	− 7.0	− 7.7	−3.9	−4.6	−3.2	− 5.9
8	− 7.0	−2.6	− 1.5	−2.5	−1.3	−3.8	1.2	− 3.3	− 7.3	− 4.8	− 4.1	−2.9	−3.5	−3.1	− 3.9
9	− 2.8	−0.1	+ 0.3	+0.1	+2.1	−1 3	+ 5.1	+ 3.4	+ 1.1	− 0.3	+ 2.3	−1.1	+0.7	−0.3	+ 1 7
10	+ 1.5	+0.3	+ 1.9	+1.5	−0.2	+2.1	+ 8.0	+ 6.3	+ 6.8	+ 5.3	+ 3.0	+1.2	+3.1	+1.2	+ 5.1
11	+ 4.4	+0.9	+ 2.2	+0.4	+0.8	+0.4	+ 7.8	+ 9.6	+10.4	+ 7.4	+ 4.4	+1.4	+4.2	+1.5	+ 6.8
12	+ 1.9	+0.3	− 0.2	+0.3	+0.2	+0.4	+ 7.4	+ 7.2	+10.4	+ 8.4	+ 6.2	+3.3	+3.8	+0.5	+ 7.2
13	+ 4.8	+1.7	+ 1.7	+1.5	0.0	+2.9	+ 6.6	+ 6.8	+13.3	+ 8.7	+ 8 2	+4.0	+5.0	+2.1	+ 7.9
14	+ 3.6	+0.5	+ 0.9	+0.9	0.0	+1.7	+ 3.4	+ 3.0	+11.3	+ 7.1	+ 6.8	+3.2	+3.5	+1.2	+ 5.8
15	+ 3.6	+1.4	+ 0.4	+0.2	+0.5	+2.2	+ 4.7	+ 3.4	+ 9.3	+ 5.4	+ 5.0	+2.4	+3 2	+1.4	+ 5 0
16	+ 2.6	−0.3	− 1.2	−2.5	−1.3	−2.7	+ 1.0	+ 1.0	+ 8.2	+ 4.9	+ 3.3	+2.4	+1.2	−1.0	+ 3.5
17	+ 1.2	−1.4	− 2.0	−1.1	+0.5	−0.6	+ 1.0	+ 1.2	+ 4.7	+ 4.2	+ 3.2	+1.7	+1.0	−0.6	+ 2.7
18	− 2.8	−1.5	− 2.0	−2.3	−3.8	−6.1	− 2.6	− 3.4	+ 2.8	+ 1.7	+ 3.1	−1.8	−1.6	−3.1	0.0
19	+ 0.2	−1.2	− 0.8	−0.5	+0.8	−1.2	− 1.4	− 0.7	+ 4.9	+ 2.0	+ 0.9	+1.4	+0.4	−0.4	+ 1.2
20	− 0.8	−6.6	− 0.6	−0.6	+0.1	−1.9	− 0.5	− 2.2	+ 3.4	+ 2.7	0.0	+0.3	−0.1	−0.8	+ 0.6
21	− 0.4	−0.4	− 1.3	−0.2	−0.6	+0.3	− 2.2	+ 1.7	+ 1.2	+ 1.7	+ 0.6	+0.8	+0.2	−0.2	+ 0.6
22	+ 1.0	+1.2	+ 0.1	+0.1	+0.5	0.0	0.0	+ 2.3	+ 0.2	− 0.9	+ 0.2	+1.7	+0.5	+0.5	+ 0.6
23	+ 2.4	−0.3	+ 1.5	+2.2	−0.2	+4.9	+ 0.7	+ 0.4	+ 2.7	− 1.5	+ 0.8	+0.1'	+1.1	+1.8	+ 0.6
24	+ 0.2	−0.8	− 1.1	+5.2	+2.7	+3.5	− 1.1	− 0.3	− 3.1	− 2.4	0.2	+2.2	+0.4	+1 6	− 0.8
days ded	27	30	23	21	20	17	29	30	28	30	29	26	310	138	172

*October 1932 to March 1933.   †April 1933 to September 1933.

eastward component includes 310 days. The range of the northward component is 14 mv/km on the curve for all days and a little over 11 mv/km on that for calm days; practically all the difference between the two curves is a pronounced reduction in the amplitude of variation at night. The curves are essentially of double period with maxima at about 5ʰ and 16ʰ (150° west meridian time) and minima just before noon and midnight. Curves for the two half-year periods are given for calm days only in Figure 4. The same type of diurnal variation is found to persist throughout the year with a considerably smaller range, 7 to 9 mv km, denoting less activity during the winter, and a corresponding increase, 17 to 22 mv/km, when the Sun is high. Reference to the successive data for individual months shows this seasonal change progressively.

The eastward curves are much less consistent in this respect. The winter curve for this component in Figure 4 is essentially the same as the corresponding northward curve except for a reversal in sign and a somewhat smaller amplitude. This relationship between the two components is almost exactly that shown throughout the year in the short-period fluctuations during which a given positive deflection to the northward is always accompanied by a negative eastward deflection about half as great and vice versa. There is therefore a distinct tendency for the current-flow to restrict itself to a direction back and forth along a line about

TABLE 5—*Diurnal variation eastward earth-current gradient in millivolts per kilometer, College-Fairbanks Polar-Year Station, for ten calm days per month recorded October 1932 to September 1933*

(Tabular values are average departures from mean of day of 60-minute means centering on the half hour, a positive sign indicating current flowing eastward is greater than mean of day.)

150° west M.M.T. hours	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Means Ann-ual	Means Win-ter*
0– 1	− 1.1	+0.5	+ 1.7	−0.8	+1.0	+2.5	− 7.4	− 1.9	− 9.2	− 3.7	− 5.8	−2.1	−2.2	+0.6
1– 2	− 1.4	+0.4	+ 0.4	−1.7	−0.8	0.0	− 7.1	− 3.6	−10.0	− 5.2	− 3.5	−2.8	−2.9	−0.5
2– 3	− 4.6	+0.5	− 1.7	−0.1	−0.4	+0.4	− 5.8	− 4.4	−12.8	− 8.6	− 7.6	−4.5	−4.1	−1.0
3– 4	− 2.8	−0.6	− 0.3	−2.8	−0.5	−0.8	− 7.9	− 4.7	−16.7	− 9.1	− 8.7	−4.7	−5.0	−1.3
4– 5	− 3.2	−0.5	− 0.3	−2.6	−1.3	−0.7	−11.0	− 7.5	−17.4	− 8.5	− 9.0	−3.5	−5.5	−1.4
5– 6	− 1.7	−0.4	+ 0.2	−0.4	+0.1	−2.7	− 9.0	− 4.4	−13.7	− 8.4	− 8.2	−4.5	−4.4	−0.8
6– 7	− 6.0	+1.2	0.0	−0.7	−0.8	−4.5	− 0.4	− 2.9	−10.8	− 7.0	− 5.7	−5.0	−3.6	−1.8
7– 8	− 6.6	−0.8	− 0.6	−1.0	−1.4	−3.4	+ 0.8	− 2.0	− 6.3	− 4.8	− 3.0	−2.1	−2.6	−2.3
8– 9	− 1.2	+0.4	+ 1.0	+1.1	+0.2	0.0	+ 4.9	+ 3.2	+ 2.0	− 0.3	+ 1.4	+0.2	+1.1	+0.3
9–10	+ 2.3	+0.8	+ 1.7	+1.7	+1.0	+2.7	+ 7.6	+ 7.9	+ 8.2	+ 5.3	+ 6.2	+2.4	+3.9	+1.5
10–11	+ 3.4	0.0	+ 2.6	+0.6	+2.0	+2.0	+ 9.9	+ 8.3	+11.3	+ 7.4	+ 6.4	+2.4	+4.7	+1.8
11–12	+ 1.2	+0.2	− 1.2	+1.1	+0.3	−0.2	+10.0	+ 6.7	+12.1	+ 8.4	+ 9.6	+2.8	+4.2	+0.2
12–13	+ 6.9	+2.8	+ 2.5	+1.2	0.0	+3.8	+11.6	+ 8.4	+15.2	+ 8.7	+ 9.4	+5.8	+6.4	+2.8
13–14	+ 5.0	+2.7	+ 1.3	+1.1	+0.2	+3.0	+ 7.2	+ 6.2	+12.5	+ 7.1	+ 7.7	+5.4	+5.0	+2.2
14–15	+ 5.9	+2.7	+ 0.2	+0.8	+1.4	+2.3	+ 8.9	+ 4.1	+ 9.7	+ 5.4	+ 4.9	+5.1	+4.3	+2.2
15–16	+ 5.9	−1.6	− 1.6	−1.2	−0.1	−1.2	+ 1.9	+ 2.7	+ 8.8	+ 4.9	+ 5.1	+3.2	+2.2	0.0
16–17	+ 5.8	−0.1	− 1.2	−0.8	−0.1	−0.1	+ 2.3	+ 0.9	+ 8.6	+ 4.2	+ 4.2	+3.3	+2.2	+0.6
17–18	− 1.6	−1.5	− 2.4	−1.4	−3.1	−5.7	− 1.3	− 4.6	+ 4.1	+ 1.7	+ 2.1	−0.1	−1.1	−2.6
18–19	− 0.5	−0.6	− 0.7	+0.7	+0.3	−0.4	− 0.1	− 2.2	+ 5.3	+ 2.0	+ 2.1	+1.1	+0.6	−0.2
19–20	− 1.3	−1.1	− 0.2	+0.2	+0.4	−0.7	− 1.9	− 2.5	+ 4.7	+ 2.7	+ 1.5	−0.3	+0.1	−0.5
20–21	− 0.1	+0.3	− 0.1	0.0	+0.7	−0.2	− 2.5	− 1.7	+ 2.7	+ 1.7	− 1.0	−1.1	−0.1	+0.1
21–22	+ 0.6	−0.4	− 0.1	+0.8	+0.2	−0.2	− 3.5	− 1.5	− 0.4	− 0.9	− 2.9	−0.3	−0.7	+0.2
22–23	− 1.4	−1.6	− 0.4	+1.9	−0.3	+2.2	− 2.1	− 3.3	− 1.7	− 1.5	− 3.0	−0.7	−1.0	+0.1
23–24	− 3.6	−3.4	− 0.5	+3.5	+0.7	+0.9	− 5.4	− 2.0	− 6.2	− 2.4	− 4.5	−0.2	−1.9	−0.4

*October 1932 to March 1933.   †April 1933 to September 1933.

30° west of north. The eastward curve of diurnal variation in the summer on the other hand, differs quite a little from the corresponding northward curve. The harmonic analysis shows that the second harmonic increases from winter to summer in about the same proportion as does that of the northward curve but the general character of the eastward curve is

TABLE 6—*Fourier analyses of diurnal variations of earth-current potential-gradient, College-Fairbanks Polar-Year Station, October 1932 to September 1933*

Component	Period	Amplitudes				Phase-angles			
		c_1	c_2	c_3	c_4	ϕ_1	ϕ_2	ϕ_3	ϕ_4
		mv/km	mv/km	mv/km	mv/km	°	°	°	°
Northward	All days (318)	0.7	6.0	1.5	0.7	90	308	221	355
	Ten calm days per month								
	Winter*	1.0	2.3	0.6	0.9	154	314	182	325
	Summer†	4.1	5.0	0.6	0.7	132	305	174	20
	Year	2.5	3.6	1.1	0.7	136	308	176	349
Eastward	All days (310)	3.1	2.9	0.4	0.2	227	108	21	300
	Ten calm days per month								
	Winter*	1.0	1.2	0.3	0.3	241	91	223	284
	Summer†	7.5	3.1	0.6	0.3	240	117	351	304
	Year	4.3	2.1	0.2	0.3	240	189	320	300

*October 1932 to March 1933.   †April 1933 to September 1933.

altered by a quite disproportionate increase in the relative amplitude of the first harmonic and it becomes quite distinctly a single-period curve. The mean curve for the year is intermediate between the two, resembling the summer curve the more because of the greater activity during that time. The mean range of the eastward curve is 11 or 12 mv/km, the range dropping to 5 or 6 mv/km in the winter and reaching 18 or 19 mv/km in the summer.

The diurnal-variation data are presented in a different way in Figure 5. The seasonal changes and the manner in which the variations are
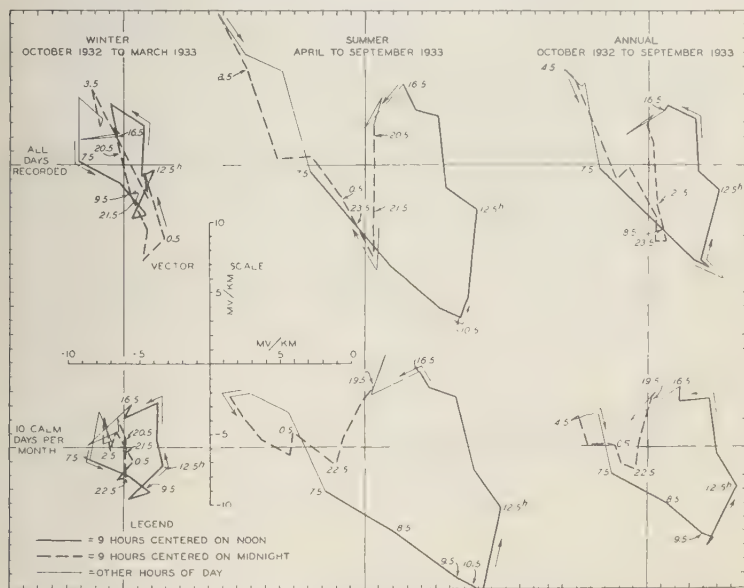
FIG. 5—HODOGRAPHS SHOWING SEASONAL CHANGES EARTH-CURRENT DIURNAL-VARIATION, OCTOBER 1932 TO SEPTEMBER 1933, COLLEGE-FAIRBANKS POLAR-YEAR STATION

affected by disturbances are more readily apparent in these hodographs than in the time-curves for the separate components. Comparing calm-day and all-day records the most noteworthy feature is the similarity of the daylight portions of the two graphs of each pair. Since the large-short period disturbances previously referred to are confined almost exclusively to the night the differences between the calm-day and all-day hodographs are due in a great measure to them. It is possible that if the recording were continued for a longer period considerable difference in the night portions of the graphs might be noted but it is hardly likely that there would be any appreciable change in the daylight sections. The seasonal change in the hodographs is mostly a change in amplitude, particularly as far as the northward component is concerned. Some change in the configuration of the graph does enter, however, due to the change in the type of the recorded variations of the eastward component.

Just how accurately the curves and graphs synopsize earth-current behavior in the region it is difficult to say. Unfortunately considerations of time and expense precluded in this instance the installation of dupli-

4

cate recording-systems such as those at Watheroo and Huancayo, so that independent check-measurements are not available. Without them the only criteria at hand are the consistency of the records from time to time and comparison with the results at other places. Weighed against these factors the records for the northward component appear to be satisfactory and reliable. So also do those for the eastward component during the winter months. This is borne out by the results of the three-point recording carried on at that time. The summer records of the eastward component are, however, open to suspicion on four counts as follows:

(1) Carefully checked records obtained at other places indicate that the seasonal changes in earth-current activity are chiefly changes in amplitude rather than in type, whereas the type of variation recorded for this component changed radically during the summer.

(2) The fact that this change consists of a trend towards a single-period curve makes it more disquieting since the effect of certain electrode-effects associated with changes in temperature or in moisture-conditions tends to produce single-period variations. Exactly this type of distortion has been detected and traced to electrode-effects on the multiple recording system at Watheroo.[4]

(3) The direction of current-flow as shown in short-period disturbances is closely restricted. Where this condition holds, as it does at Watheroo and Huancayo, it is reflected in a similar and fairly constant phase-relationship between the two components of diurnal variation. As noted before the direction of current-flow indicated by the winter diurnal-variation curves is the same as that during disturbances. Hence the same relationship would be expected to continue during the summer.

(4) Comparison of the calm-day and all-day curves for the northward component shows a fairly constant difference between the two, marked by a reduction in the night-time activity on calm days. The same is true for the eastward component during the winter, but in the summer the calm-day and all-day curves are almost identical. This again suggests that some factor other than the activity of the earth-currents may be acting to determine the character of the recorded variations.

In view of the scarcity of earth-current records from polar regions it is unfortunate that the data must be presented with these reservations. Even allowing for them it is believed that the more general features of the variations are established sufficiently to be of value in the consideration of earth-currents as a phenomenon of world-wide distribution. It is of course possible that the records from other stations where such measurements were made during the Polar Year may confirm the indications of the eastward records even on these questionable points.

Magnitude of the earth-currents So far only brief mention has been made of the magnitude of earth-currents at College-Fairbanks. The mean range of diurnal variation in potential gradient was found to be between 11 and 14 mv/km for the northward component and a little less for the eastward component. This gives for the resultant a range of from 15 to 18 mv/km. The corresponding ranges at Watheroo and Tucson respectively are 1.1 and 2.5 mv/km approximately. The more tenable theories of earth-current flow suggest that the diurnal variation near the poles should be less pronounced than at middle-latitude stations, although sufficient data are not available for reliable prediction on this point. Hence, the ranges in potential gradient observed at College seem at first

glance to be quite out of line with theory since, instead of being smaller than those at Watheroo and Tucson they are from six to fifteen times as great. However potential measurements can not define current-flow — the resistance of the path must also be considered. The average resistivity of the soil at Watheroo is roughly 1000 ohm-cm and that at Tucson is also low, measurements near the Observatory giving a mean value around 3000 ohm-cm. No resistivity-measurements were made at College but in view of the fact that the sub-soil there is for the most part permanently frozen right down to bedrock, resistivity-values a hundred or more times as great as those at the other stations would not be at all surprising. The contact-resistances of electrodes S and E give some indication of the magnitudes which the resistivity of frozen soil can reach; the maximum resistances measured correspond to soil-resistivities well over a megohm-cm. Hence the diurnal-variation records do not mean that the current-densities here are greater, but that they are comparatively smaller.

The really surprising magnitudes are those of the short-period fluctuations—even allowing for the high resistivity of the region. The high ratio of their amplitudes to that of the diurnal variation has already been referred to but the amount of disturbance is more readily realized when it is expressed in millivolts per kilometer. Deflections of 1000 millivolts (or one volt) per kilometer are found frequently in the records often taking the form of rapid oscillations with amplitudes of that order of magnitude so that changes as great as two volts per kilometer in a few minutes are sometimes observed.

Comparison with magnetic and auroral records—Until the reduction of the magnetic records of the Station has been completed a detailed comparison of the two sets of records cannot be made. A cursory examination of the grams indicates that the same qualitative interrelationship between the two phenomena holds here as at other stations, at least as far as pronounced disturbances are concerned. Just how well the relationship between the diurnal variations of the two agrees with theory must be left for later determination.

A comparison of the earth-current records with the systematic auroral observation carried out by V. R. Fuller at College during the Polar Year has been summarized in a previous paper.[5] Considerable agreement is found between the auroræ and disturbances in the earth-current records; coefficients of linear correlation from 0.71 to 0.76 were obtained using different measures of disturbance. Effects associated with brilliant isolated auroral displays seen at College are readily detected in the earth-current records, not only at that Station, but also at Tucson (Arizona) and, in exceptional cases, as far south as Huancayo (Peru). Oscillatory disturbances in the earth-current records and moving types of auroræ, respectively, seem to show the highest degree of correlation.

The authors wish to acknowledge their indebtedness to Dr. J. A. Fleming, Acting Director of the Department of Terrestrial Magnetism, to whose efforts the successful establishment of the College-Fairbanks Station are in a large measure due, and to O. H. Gish, Assistant Director, to whom the design of the apparatus should be attributed and under whose direction the work was done.

[5] W. J. Rooney, Terr. Mag., **39**, 103-109 (1934).

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REVIEWS AND ABSTRACTS

FILCHNER, W.: *Kartenwerk der Erdmagnetischen Forschungsexpedition nach Zentral-Asien 1926-28.* Erster Teil: China–Tibet I. Petermanns geogr. Mitt., Gotha, Ergänzungsheft Nr. 215, 1933 (255 mit 8 Karten).

In 1903-04 Dr. Wilhelm Filchner made an important scientific expedition to China and Northeastern Tibet, the results of which were published at Berlin in 1906-14 in ten volumes and an atlas. About ten years ago he began to lay plans for another expedition to this territory primarily for studying the distribution of the magnetic elements and increasing our knowledge of the secular variation, particularly in Tibet where very little magnetic work had previously been done. The German Foreign Office and the Notgemeinschaft der Deutschen Wissenschaft provided means for his instrumental equipment and for starting him on his way but for the greater portion of the expedition he was himself obliged to raise additional funds chiefly through generous contributions by friends. The record of the journey is one of courage, resourcefulness, and confidence and has been described in the author's interesting popular narrative "Om mani padme hum" (Leipzig, Brockhaus, 1929).

The itinerary of the 1926-28 expedition was as follows: After standardizing his magnetic instruments at the Potsdam Observatory, Dr. Filchner proceeded via Moscow to Tashkent whence he continued in the spring of 1926 via Ili through Dzungaria to Tihwa (Urumchi) where he remained from the first of May until the end of June. His journey then led via Hami to Siningfu and Lussar. In the nearby monastery of Kumbum he passed the winter of 1926-27, suffering from cold and hunger. In May 1927 he was able to set out in a southwesterly direction towards Lhassa and in mid-September reached Nag-Tochu-Ka whence he began his journey the first of November directly across Tibet from east to west and out through Kashmir to India.

The magnetic results of the expedition were reduced by O. Venske and published by the Prussian Meteorological Institute in 1931. A brief abstract of this work was published in this JOURNAL (**36**, 1931, p. 253). In the volume before us are presented the topographical data resulting from well-spaced observations and sketches made by the author along his route from Sining to Tangla in four excellent maps constructed, on the scale of 1/500,000, by O. Wand and G. Scholz under Dr. Filchner's supervision. When completed the work in Tibet will make five additional sheets but lack of funds prevents their publication at present. These maps produced in color form a most valuable contribution to the cartography of Asia. The accompanying text contains an extremely detailed description of the country traversed, interspersed with line-cut sketches of outstanding natural and cultural features. In the "Bemerkungen zum Kartenentwurf" (pp. 226-241), O. Wand has explained minutely the procedure followed in preparing the charts.

Considerable difficulty was encountered in the transliteration of the native geographic names, particularly of rivers, mountains, etc. Dr. Filchner made careful notes of the local pronunciation on the spot and whenever possible had the names written down by the inhabitants. Dr. W. A. Unkrig made an exhaustive study of this material and arranged in an alphabetical list the names appearing on the charts and sketches in six columns, namely, adopted spelling, map references, Tibetan, Mongolian, and Chinese characters when available, and finally a translation of the names into German. This catalogue occupies pages 20-86 of the text.

Of particular interest to geophysicists who may some day follow the route of Dr. Filchner, are four additional sheets at the end of the volume which present sketches of 120 magnetic stations. These show the sites of the stations with reference to surrounding objects and topographical features the purpose being to facilitate their reoccupation for obtaining secular-variation data.

It is greatly to be hoped that funds may soon be found for completing the publication of the results of this important expedition which was successfully accomplished through remarkable courage and perseverance in the face of almost insurmountable difficulties including the mistrust and hostility of the native population of the region traversed. At the end of his journey Dr. Filchner was so exhausted from illness, hunger, and exposure to the elements that he stated he would have been physically unable to carry through a set of observations at a single additional station. The valuable data collected, particularly those pertaining to terrestrial magnetism and topography, must certainly go far to recompense the traveler for his suffering and illness, and give much satisfaction to his friends in China who made possible the completion of the enterprise by their aid and contributions.

H. D. HARRADON

TWENTY-SEVEN DAY RECURRENCES IN TERRESTRIAL-MAGNETIC AND SOLAR ACTIVITY, 1923–1933

BY J. BARTELS

The well-known effect of the Sun's rotation on terrestrial-magnetic activity has been demonstrated in a diagram showing the 27-day recurrence phenomenon in the international magnetic character-figures C for the years 1906–1931.[1] Another diagram is given here, showing side by side, in a somewhat improved and simplified manner, the recurrence phenomenon for the last sunspot-cycle 1923 to 1933 in terrestrial-magnetic activity (C) and solar activity (relative sunspot-numbers R for the central zone).[2] As before, each day is represented by a square containing one of seven symbols indicating various degrees of activity; the days are arranged in horizontal rows of 27, but, for continuity, the six first days of the next row are added at the right. The date of the first day in each row is indicated on the left. For future reference, the horizontal rows— or rotations—have been numbered beginning with the first row (first day, January 11, 1906) of the former diagram; these numbers for Figure 1 are 231 to 378 and are indicated in the space between the magnetic and solar diagrams. In order to obtain a clear diagram, the symbols are assigned as follows:

Group	0	1	2	3	4	5	6
Symbol	White square	Small dot	Small ring	Larger ring	Black circle	Black octagon	Black square
C	0.0 to 0.1	0.2 to 0.3	0.4 to 0.7	0.8 to 1.0	1.1 to 1.3	1.4 to 1.6	1.7 to 2.0
R	0	1 to 8	9 to 18	19 to 29	30 to 46	47 to 61	over 62

A total of 3996 days has been plotted; the number of days in each group, calculated on the average per 1000 days, is:

Group	0	1	2	3	4	5	6
Frequency of C......	196	165	244	188	113	58	36
Frequency of R......	389	105	174	139	109	49	35

The high frequency of days with $R = 0$ prohibits a better choice of the lower groups, aiming at higher resemblance of the two frequency-distributions; however, in the higher groups of activity 4 to 6, which form, so to speak, the backbone of the [vertical] sequences of disturbed days, the frequencies of C and R agree satisfactorily.

The magnetic diagram will be found convenient in determining the sequences to which a magnetically disturbed or magnetically quiet day belongs, especially since it includes the period of the Second International Polar Year beginning August 1, 1932. Beyond this practical side, it illustrates, in new observational material, the general results of the former paper. The exceptional length of the sequences at the end of the eleven-year cycle (from about 1929) is striking, as compared with the rather

[1] J. Bartels, Terr. Mag., **37**, 1-52 (1932); see also H. W. Newton, Observatory, **55**, 256-261 (1932).

[2] C has been taken from the annual tables published in this JOURNAL, R from the "Bulletin for character-figures of solar phenomena," published quarterly, for the International Astronomical Union, by the Eidgenössische Sternwarte, Zürich.
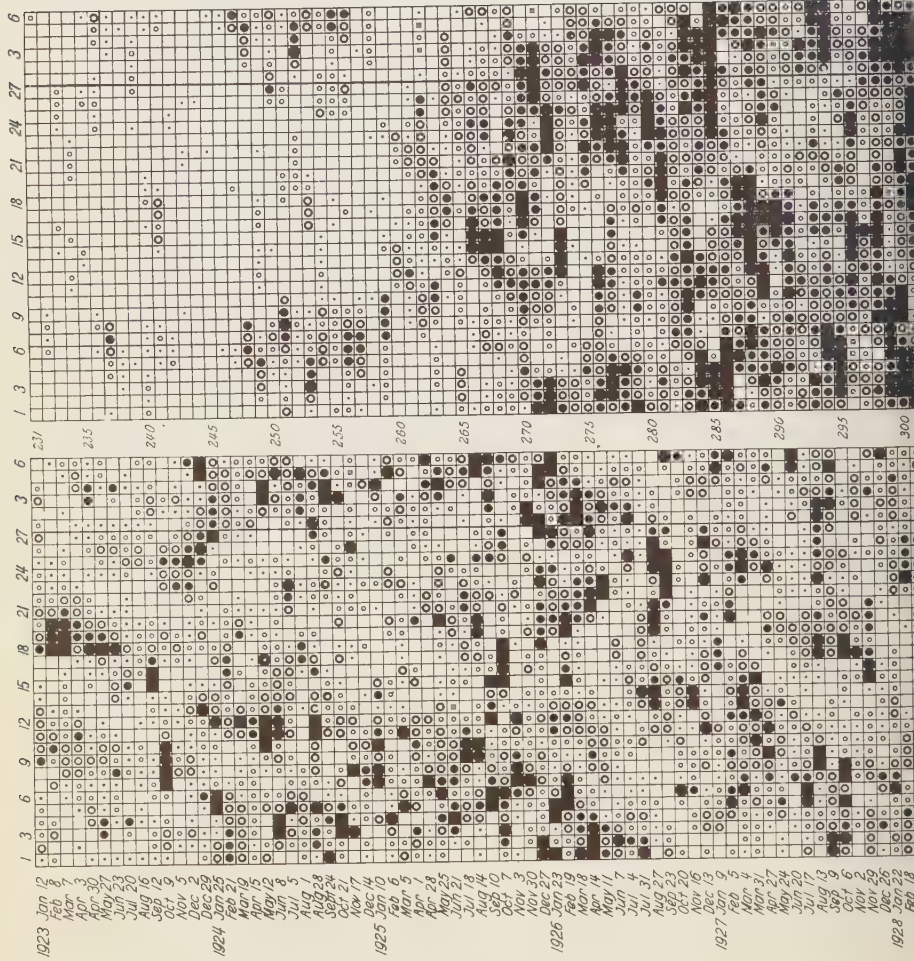
spotty appearance at the beginning (the fine sequence in 1923 belongs to the preceding cycle).
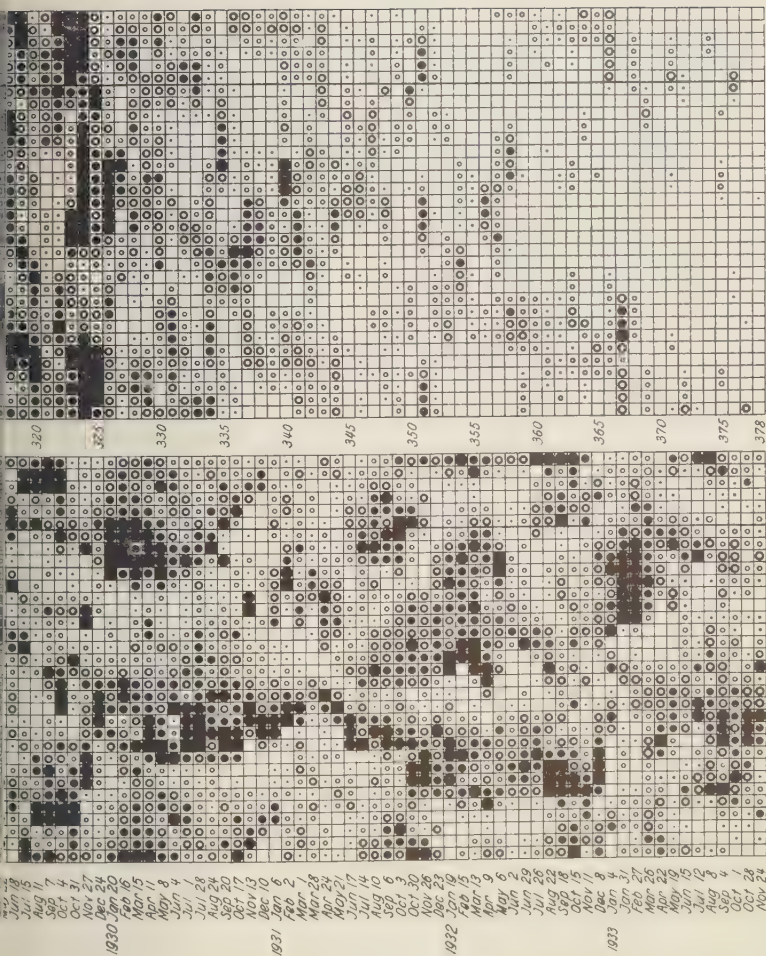
As to the solar diagram, its main purpose is to invite comparison with the magnetic diagram and reexamination of the results obtained formerly.[3] The last years 1930 to 1933 illustrate again the fact that strong and long-lived magnetically active regions on the Sun persist through long times in which the Sun appears practically spotless, or, in other words, that small or zero sunspot-numbers comprise many different degrees of solar activity with respect to its geophysical influences. The relative sunspot-numbers for the central zone [with a diameter half that of the Sun's disc] have been chosen instead of those for the whole disc because a group of sunspots takes more than 13 days to cross the disc, all the time adding to the relative sunspot-number. Even so, an equatorial point of the Sun needs four or five days to cross the central zone, which accounts for the fact that the diagram for solar activity still shows more series of con-secutive days with similar activity, that is, longer horizontal stripes of equal symbols, than the magnetic diagram. This "blurring" of the solar diagram could be avoided by deriving relative sunspot-numbers for still narrower meridional sectors, but this could only be done at an astro-physical observatory and, in fact, seems hardly worth while, because it will in no way help to detect, by direct astrophysical observations, the active M-regions on the Sun indicated in the magnetic diagram.

I am obliged to Messrs. W. Zick and C. C. Ennis for work on the diagram.

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MAGNETIC ACTIVITY
INTERNATIONAL CHARACTER-FIGURES

SOLAR ACTIVITY
RELATIVE SUNSPOT-NUMBERS, CENTRAL ZONE

□ 0.0-0.1 0.2-0.3 0.4-0.7 0.8-1.0 1.1-1.3 1.4-1.6 1.7-2.0 ■

□ 0 1-8 9-18 19-29 30-46 47-61 >62 ■

FIG. 1—TWENTY-SEVEN DAY RECURRENCES IN TERRESTRIAL-MAGNETIC AND
SOLAR ACTIVITY, 1923-1933

PRESENT STATUS OF THE INVESTIGATION ON DYNAMIC AND TILTING DEVIATIONS IN THE DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON

By William J. Peters

This investigation began in 1928[1] with the study of tilting deviations produced by the inclinations of the planes of the compass-card when subjected to simple harmonic motion over or under a horizontal axis, as in the ideal rolling of a ship in a non-resisting medium or the bed of a swing under its horizontal axis. Such a swing was used in the first experiments, but the results showed the necessity of automatic action and of continuous records throughout the phases of the swing-motion, which are not possible in visual observations.

A swing was then designed and constructed in the instrument-shop of the Department. It is made entirely of brass and actuated by an electric motor installed so far away that the motor has no magnetic effect on the compasses to be used in the experiments. The record is obtained by a motion-picture camera located on the swing-frame.

Observational records by the automatic swing began in 1932 with experiments on the stability and motion of dummy, that is, non-magnetic, cards and needles, and continued through many experiments with a seven-inch standard liquid-compass (R29499) that had been used on Cruise III of the *Galilee*.

Numerous experiments were made before it was realized that the amplitude of the swing-motion would not remain constant in some investigations as the plane of the swing-motion is turned to different azimuths, that is, headings. This defect was due to small inequalities of the floor which caused slight deformations of the swing-frame, and was overcome by installing a hardwood, level track.

Subsequent experiments revealed other masking effects upon the deviations and the difficulty of eliminating or controlling them has postponed further experimenting. These are caused by the one-sidedness of the impulses actuating the swing, the combined pendulous and sliding motion of the card on the pivot-point, and the location of the effective center of mass out of the north-south vertical plane of the card.

As an illustration, the numerical results of one series of experiments are given in Tables 1 and 2 for compass R29499; these were made May 18-25, 1933, with the special object of comparing simultaneous readings by the forward and after lubber-lines, respectively. The compass was installed with its pivot-point 180 cm below the axle of the swing. The full period of the swing is 2.57 seconds. The following conventions were adopted. The two ends of the axle, bed, etc., are distinguished by the nautical terms "forward" and "after" with the motion-picture camera installed abaft the compass, a convention which also defines starboard and port. The compass is usually installed above the axis of roll in a ship, whereas it is below the axle of the swing. Hence to measure the amplitudes in the same direction in the two cases, an amplitude is called starboard when the compass has swung to port from the position of rest.

The first line of entries in Table 1 gives the means of five to ten readings of the card taken from the motion-picture film at the extremes of the card-oscillations by the forward and after lubber-lines, respectively.

[1]William J. Peters, Terr. Mag., **34**, 93-115 (1929); also Compass and dip-circle deviations caused by harmonic motion, Proc. Internat. Oceanogr. Cong., Seville, 135-146 (1929).

TABLE 1—*Data from motion-film records obtained in automatic swing,*

Value	Head-ing	Lubber-line readings Forward Max.	Min.	After Max.	Min.	Amplitude of swing, ψ s	p	Head-ing	Lubber-line readings Forward Max.	Min.	After Max.	Min.	Amplitude of swing, ψ s	p
Means	N	s361°.02	p358°.62	s360°.80	p359°.72	+12°.2	−14°.2	S	p180°.52	s179°.30	p181°.60	s179°.10	+11°.7	−14°.9
R		359°.82		360°.26					179°.91		180°.35			
ℓ		359.72		360.16					179.81		180.23			
δ		−0.10		−0.10					−0.10		−0.12			
Δ		2.40		1.08					1.22		2.50			
Means	NNE	s 20.62	p 18.16	s 20.34	p 19.28	+12.1	−14.4	SSW	p190.37	s198.23	p200.57	s198.00	+12.0	−14.7
R		19°.39		19°.81					198°.80		199°.28			
ℓ		22.56		22.88					202.29		202.75			
δ		+3.17		+3.07					+3.49		+3.47			
Δ		2.46		1.06					1.14		2.57			
Means	NE	s 40.70	p 38.40	s 40.44	p 39.58	+12.2	−14.5	SW	s219.80	p219.00	p220.80	s218.30	+11.8	−14.5
R		39°.55		40°.01					219°.40		219°.55			
ℓ		44.90		45.41					224.55		224.99			
δ		+5.35		+5.40					+5.15		+5.44			
Δ		2.30		0.86					0.80		2.50			

	s 64.66 φ 62.58	s 64.26 φ 63.80	+12.2 −14.4 WSW	φ243.55 s242.90	φ244.ro s242.50	+11.8 −14.6
Means. ENE						
R	63°.62	64°.03		243°.22	243°.60	
ι	67.24	67.62		247.25	247.65	
δ	+3.62	+3.59		+4.03	+4.05	
Δ	2.08	0.46		0.65	2.20	
	s 89.38 φ 87.82	φ 89.14 s 88.72	+12.2 −14.5 W	s268.93 φ268.37	φ269.93 s268.27	+11.8 −14.7
Means. E						
R	88°.60	88°.93		268°.65	269°.10	
ι	89.82	90.21		269.90	270.30	
δ	+1.22	+1.28		+1.25	+1.20	
Δ	1.56	0.42		0.56	1.66	
	s116.46 φ115.36	φ116.92 s115.80	+12.3 −14.5 WNW	s296.15 φ295.15	φ296.65 s295.60	+11.9 −14.7
Means. ESE						
R	115°.91	116°.36		295°.65	296°.12	
ι	112.36	112.76		292.20	292.60	
δ	−3.55	−3.60		−3.45	−3.52	
Δ	1.10	1.12		1.00	1.05	
	φ141.28 s140.44	φ142.32 s140.62	+12.3 −14.3 NW	s321.05 φ319.35	φ320.65 s320.35	+11.9 −14.5
Means. SE						
R	140°.86	141°.47		320°.20	320°.50	
ι	135.05	135.54		315.00	315.35	
δ	−5.81	−5.93		−5.20	−5.15	
Δ	0.84	1.70		1.70	0.30	
	φ161.96 s161.12	φ163.04 s160.90	+12.3 −14.6 NNW	*	*	
Means. SSE						
R	161°.54	161°.97				
ι	157.65	158.10				
δ	−3.89	−3.87				
Δ	0.84	2.14				

*Motion-film record illegible.

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Many more readings are available, but it is not expedient to incur the labor under the present conditions of experimenting, especially as the individual readings do not vary more than 0°.2.

The mean of maximum and minimum is denoted by R, which is analogous to a mean taken at sea for declination. Readings taken when the swing is at rest in the position of equilibrium are denoted by ζ and are the headings of the swing unaffected by the swing-motion. Consequently $\delta = (\zeta - R)$ represents the deviation due to the motion of the swing. The amplitude of the swing is given under ψ for port and starboard. The double amplitude of the card-oscillation, as shown by the forward and after lubber-lines, respectively, is denoted by $\triangle$, obtained from the forward and after R-entries.

TABLE 2—*Summary ψ, δ, and $\triangle$*

Head-ing	ψ				δ		$\triangle$			
	St'd S	Port P	$(S-P)\ 2$	$-(S+P)$	For'd	After	For'd F	After A	$(F-A)\ 4$	$(F+A)\ 4$
N	$+12.2$	-14.2	13.2	2.0	-0.10 -0.10		2.40	1.08	$+0.33$	0.87
NNE	$+12.1$	-14.4	13.2	2.3	$+3.17$ $+3.07$		2.46	1.06	$+0.35$	0.88
NE	$+12.2$	-14.5	13.4	2.3	$+5.35$ $+5.40$		2.30	0.86	$+0.36$	0.79
ENE	$+12.2$	-14.4	13.3	2.2	$+3.62$ $+3.59$		2.08	0.46	$+0.40$	0.64
E	$+12.2$	-14.5	13.4	2.3	$+1.22$ $+1.28$		1.56	0.42	$+0.28$	0.50
ESE	$+12.3$	-14.5	13.4	2.2	-3.55 -3.60		1.10	1.12	0.00	0.56
SE	$+12.3$	-14.3	13.3	2.0	-5.81 -5.93		0.84	1.70	-0.22	0.64
SSE	$+12.3$	-14.6	13.4	2.3	-3.89 -3.87		0.84	2.14	-0.32	0.74
S	$+11.7$	-14.9	13.3	3.2	-0.10 -0.12		1.22	2.50	-0.32	0.93
SSW	$+12.0$	-14.7	13.4	2.7	$+3.49$ $+3.47$		1.14	2.57	-0.36	0.92
SW	$+11.8$	-14.5	13.2	2.7	$+5.15$ $+5.44$		0.80	2.50	-0.42	0.82
WSW	$+11.8$	-14.6	13.2	2.8	$+4.03$ $+4.05$		0.65	2.20	-0.39	0.71
W	$+11.8$	-14.7	13.3	2.9	$+1.25$ $+1.20$		0.56	1.66	-0.28	0.56
WNW	$+11.9$	-14.7	13.3	2.8	-3.45 -3.52		1.00	1.05	-0.01	0.51
NW	$+11.9$	-14.5	13.2	2.6	-5.20 -5.15		1.70	0.30	$+0.35$	0.50
NNW^*										

*Motion-film record illegible.

These quantities are summarized in Table 2. The starboard and port amplitudes are regarded as positive and negative, respectively, and accordingly $(S - P)\ 2$ is the mean amplitude of the automatic swing. The range in this throughout the 15 headings is not more than 0°.2, whereas it was from 1° to 2° before the installation of the hardwood track. The values under $(S + P)$ are the differences in amplitude between starboard and port extremes, and are the result of the one-sided impulses actuating the swing. Since the impulse is given as the swing-amplitude changes from starboard to port, one naturally looks for semi-circular effect in δ or $\triangle$. Analyses do in fact reveal a semicircular effect in a function of $\triangle$, to which reference is made later.

The deviation δ caused by the action of the swing is practically the same by the forward as by the after lubber-line. The maximum values occur on or near the intercardinal points with opposite signs in adjacent

quadrants in accordance with equations for dynamic deviations[2]; but whereas these equations give zero for deviations on the cardinal points, the experiment shows values of about 1°.25 on east and west, and about 0°.1 on north and south headings. It is concluded, therefore, that these deviations are masked to some extent by some if not all of the three effects referred to.

The double oscillation of the card $\triangle$ increases for one lubber-line as it decreases for the other. The turning motion in azimuth of the card is represented by $(F + A)/4$, and $(F - A)/4$ represents the combined pendulous and sliding motion expressed as effects upon the card-readings. The occurrence of minimum values of $(F - A)/4$ on east-southeast and west-northwest—directly opposite headings—and maximum values on east-northeast and southwest—nearly opposite headings—seems to indicate a semicircular effect due to uneven impulses and also a location of the effective center of mass out of the north-south vertical plane of the card. The quadrantal character of $(F + A)/4$ gives some promise of correlation with the deviation if the three masking effects can be eliminated in the swing-experiments or controlled by proper corrections.

In connection with these experiments, the original declination-observations made on the *Galilee* and *Carnegie* have been examined to determine the availability of card-oscillations for empirical corrections for deviations. In the early work, observations were made with different instruments and different devices with the expectation of eliminating systematic instrumental errors. The time given to each device is, therefore, too short for reliable determinations of the magnitude of card-oscillations. The declination-observations on the *Carnegie*, especially those with the marine collimating-compass, give the magnitude of successive oscillations extending over a period of about 3.5 minutes, which is repeated four times, conditions permitting. But before these can be used for the purpose, the relation between magnitude of oscillation and deviations must be determined experimentally without masking effects, in order to determine how the investigation of correlation should proceed for sea-work.

The examination of original declination-observations also shows that some relation exists between the magnitude of card-oscillations and the agreement of the four independent declination-results usually obtained. Therefore, it seems desirable to increase the time of observing when the magnitude of oscillations increases in planning future work.

For more information in connection with simultaneous lubber-line readings in the automatic swing, actual simultaneous lubber-line readings at sea would be most desirable to determine the availability of such readings, in case the experiments warranted their use.

In conclusion, it might be pointed out that one should not be misled by the magnitude of the quantities that appear in Tables 1 and 2, which apply to a radius of about two meters and a period of less than three seconds. The deviations due to ship's motion generally do not exceed 0°.3 on a vessel of the size of the *Carnegie* or the *Galilee*, although there are no doubt instances when this value might be exceeded even on vessels of this size.

[2]William J. Peters, Terr. Mag., 34, 93-115 (1929).

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REVIEWS AND ABSTRACTS

KOLHÖRSTER, W., AND L. TUWIM: *Richtungsverteilung der Höhenstrahlung.* Ergebnisse der Kosmischen Physik, Bd. 2 (Beitr. Geophysik, Supplementband 2), 1933 (238-302). [Leipzig, Akademische Verlagsgesellschaft.]

With all honor and respect to the mathematical enthusiasm and perseverence of the late Dr. Tuwim, as evidenced also in his previous publications on the same subject, this 64-page section on what has become perhaps the most important aspect of the whole subject of the Höhenstrahlung, is a monument to calculation rather than to analytical physics. The reviewer admits his bias at once—he has never been able to comprehend why the senior author's elegant and highly analytical coincidence-method was made evidently secondary in Kolhörster's own laboratory to the single-tube counter-method of Tuwim, the latter condemned from the start by its inadequate resolving-power (in a very general experimental sense). This article was probably written before the coincidence-method began to bear its rich fruits, especially in the hands of Johnson and Rossi, but it sufficiently illustrates the weakness of the single-tube counter-method. Two pages are allowed for a mention of the vertical and azimuthal directional variations as determined by the coincidence-method. One paragraph disposes of the directional effect data obtained by cloud-chamber experiments (the only other really analytical experimental attack in the field). More than thirty pages are devoted to presenting the involved calculations essential to interpreting the inadequate and almost ambiguous directional data of single-tube counter-experiments. Effects of atmospheric absorption and scattering are treated for certain mathematically ideal cases. A summary is given of "directional" experiments with ionization-chambers (various openings in thick shields). The sketchy experimental data obtained by use of the single-tube counter-method occupy one page. Calculated tables of certain special functions required by the method occupy many pages. A restricted bibliography is appended.

The extension of our knowledge of the penetrating radiation by the cloud-chamber and coincidence-methods during the past two years made this section out of date before it was printed.

M. A. TUVE

HAALCK, H.: *Lehrbuch der angewandten Geophysik.* Berlin, Gebrüder Borntraeger, 1934 (vii + 376 mit 142 Textfiguren und 6 Taflen). 23 cm. Preis: geh. 24 RM 24, geb. RM 26.

The rapid development of methods of geophysical prospecting since the World War has been attended with an ever-increasing output of literature on all aspects of the subject including, in addition to specialized treatises, a number of excellent general summaries the object of which is to afford a comprehensive idea of the present status of the subject. However, the need has been felt for a brief practical text-book covering all methods, particularly adapted to the needs of students and practicing engineers. The present volume admirably satisfies that need. In it stress is especially laid on the practical application of the different methods, particularly from the standpoint of physics and geology, theory being introduced only so far as required for the explanation of the methods and only the mathematical formulas requisite for adequate exposition have been presented. Illustrative examples have been chosen from existing literature which are especially instructive for the respective methods.

Following a suitable introduction in which the rôles of the various methods are briefly sketched, and a succinct historical note on geophysical prospecting from the 17th century down to recent times, is presented, the five principal chapters are devoted respectively to the five principal methods, namely, gravimetric, magnetic, electric, seismic, and radioactive. Each chapter contains an adequate discussion of the method treated with description of the instruments and technique employed, together with such data as are available on the constants and physical characteristics of the earth-materials involved in the interpretation of the results and the practical application of the measurements.

Even though the development of applied geophysics is still in progress, the present concise exposition with its abundant though carefully selected bibliographical references will be welcomed as a text- and reference-book by students and engineers interested in the subject of applied geophysics.

W. J. ROONEY

CRITICAL-FREQUENCY OBSERVATIONS OF THE *E*-LAYER AT THE HUANCAYO MAGNETIC OBSERVATORY

By H. W. Wells

Abstract—This paper describes the nature and characteristics of the reflections from the *E*-layer of the ionosphere as observed at the Huancayo Magnetic Observatory, and gives a comparison of the results obtained with similar investigations in the higher latitudes.

It is shown that no marked critical frequencies are in evidence, and that the transition from the *E*-region to an upper ionized layer, or vice versa, is a gradual process with little evidence of the long retardations which are frequently observed in the higher latitudes. There is, however, a definite and smooth diurnal variation of estimated maximum ionization which peaks around noon. The results indicate that the refractive index of the electromagnetic waves returned from the region of the maximum ionization of the *E*-layer is complex and that dissipation is appreciable. Epstein's conclusion, that if the collisional frequency is large, part of the energy will be reflected and part transmitted, is borne out by these observations. It may be noted that this appears to be the necessary condition for the qualitative fulfilment of the so-called "atmospheric-dynamo" theory of diurnal variation of the Earth's magnetic field.

INTRODUCTION

When the apparatus for the exploration of the ionized regions of the upper atmosphere was installed in April 1933 at the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington in Peru, it soon became apparent that the results would prove of great interest to a number of investigators. This paper treats only one phase of the ionosphere-investigations, namely, the nature and characteristics of the reflections from the *E*-layer, which is the lowest identified ionized region at about 100 km.

The apparatus and the method of investigation used in obtaining these data have been completely described in a previous paper.[1] This equipment consists of three essential pieces, namely, transmitter, receiver, and synchronous oscillograph-unit with associated apparatus. A mechanical chopper and the driving motor for the three-sided mirrors in the oscillograph-unit are operated from a constant 60-cycle power-supply.

Radio-frequency pulses of short duration are transmitted at a rate of 90 per second. The receiver picks up the ground-wave as well as the pulse-echoes from the upper ionized regions. The time-retardation between the patterns shown on the oscillograph-screen is then measured directly in terms of kilometers of virtual height of the layer or layers returning the signals. This method is a modification of the original plan as developed by Breit and Tuve of the Department of Terrestrial Magnetism. The observations reported upon have been obtained by the manual technique.

The Huancayo Magnetic Observatory is in latitude 12° 02′.7 south and longitude 75° 20′.4 west, is 11,000 feet above sea-level, and is unique for investigations of this nature.

[1]Berkner and Wells, Report of ionosphere-investigations at the Huancayo Magnetic [Observatory (Peru) during 1933, Proc. Inst. Radio Eng., **22**, 1102-1123 (1934).

Results

Results of investigations extending over a period of more than a year show the nature of the reflections from the region of maximum ionization of the E-layer of the ionosphere over this location to be somewhat different from that which has been reported frequently in the higher latitudes.[2-8]
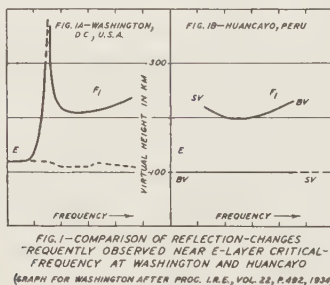

FIG. 1—COMPARISON OF REFLECTION-CHANGES
"FREQUENTLY OBSERVED NEAR E-LAYER CRITICAL-
FREQUENCY AT WASHINGTON AND HUANCAYO
(GRAPH FOR WASHINGTON AFTER PROC. I.R.E., VOL. 22, P.492, 1934)

Figure 1 illustrates typical determinations of the critical or "penetrating" frequencies for the E-region, both at Washington and at Huancayo. The symbols used in the figures are defined as follows: V, varying reflection-amplitude; B, reflections of large amplitude; M, reflections of intermediate amplitude; S, reflections of small amplitude; Vy, "very" used to modify B, S, etc.; M_1, M_2, etc., first multiple, second multiple, etc. The arrows on the figures indicate to scale the height-range through which echoes from a given layer are received.

It will be noticed that, for Huancayo, no definite critical frequency is apparent. For example, at Washington, as the frequency is increased from a frequency at which the reflections are returned from the E-layer only, an increase in the virtual height of the echoes is frequently observed as the critical frequency is approached. These retardations become very great, reaching a maximum virtual-height or even disappearing entirely at or near the critical frequency. Having just passed through f_E, the echoes are then returned from the next higher ionized region but still suffer retardations in the E-layer. As the frequency is further increased, the virtual heights fall to values approaching the actual height of the upper region as the effect of the E-layer upon the group-retardation is diminished.

At Huancayo, however, none of the above-mentioned characteristics of the E-layer has been noted during any of the observations which cover a range from 1750 to 4000 kc. At low frequencies, the reflections are returned entirely from the E-layer. The echo-pattern is not sharp, but may often vary from virtual height of 100 km up to 200 km or more, although the lower limit remains quite constant. As the frequency is increased, no increased retardations are in evidence, but a very weak

²Appleton and Green, Proc. R. Soć. A, **128**, 159-178 (1930).
³Schafer and Goodall, Proc. Inst. Radio Eng., **19**, 1434-1445 (1931).
⁴Appleton and Naismith, Proc. R. Soc. A, **137**, 36-54 (1932).
⁵Appleton and Builder, Proc. Phys. Soc. London, **44**, 76-87 (1932).
⁶Appleton, Nature, **131**, 872 (1933).
⁷Gilliland, Bur. Stan. J. Res., **11**, 141-146 and 561-566 (1933).
⁸Kirby, Berkner, and Stuart, Bur. Stan. J. Res., **12**, 15-51 (1934); also Proc. Inst. Radio Eng., **22**, 481-521 (1934).

echo appears at a virtual height generally between 190 and 250 km, thus indicating that a portion of the energy is penetrating the E-region and is being returned from an upper layer. As the frequency is further increased, the amplitude of the echo from the E-region gradually diminishes while that of the echo from the upper region gradually increases.

During this entire transition there is no apparent change in the virtual heights of the signals returned from the E-region. There is often a very small decrease in the virtual heights of the echoes from the upper layer as the intensity builds up, but this change is very small (see Figs. 2, 3, and 4).
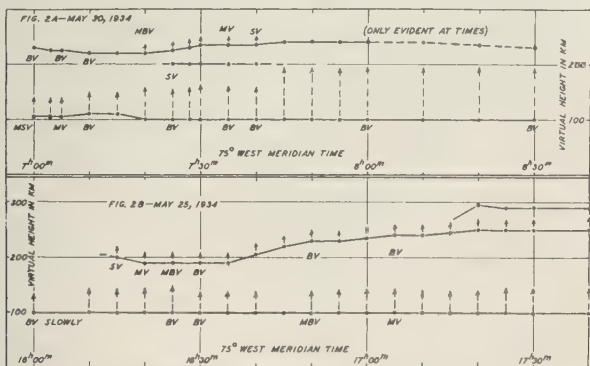
FIG. 2—CONTINUOUS RECORDING ILLUSTRATING REFLECTION-TRANSITION FROM E- TO F-LAYER, FREQUENCY 2500 KC, HUANCAYO MAGNETIC OBSERVATORY
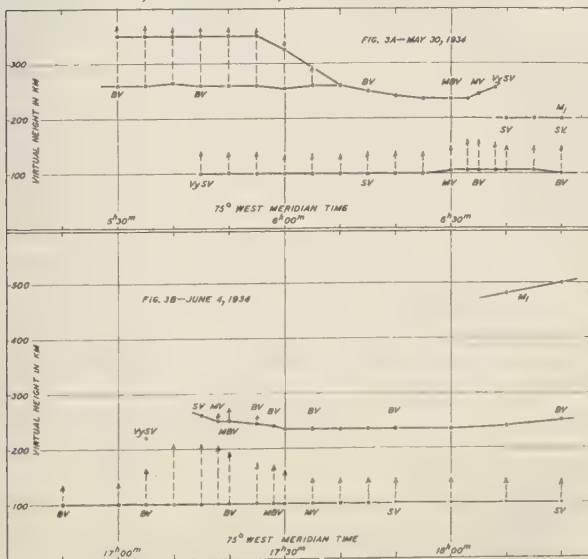
FIG. 3—CONTINUOUS RECORDING ILLUSTRATING REFLECTION-TRANSITION FROM E- TO F-LAYER, FREQUENCY 1750 KC, HUANCAYO MAGNETIC OBSERVATORY

To eliminate any possibility of passing over a definite critical fre-
quency in the frequency-change method where the frequency is increased
in steps of 50 or 100 kc, a number of continuous recordings have been
made at fixed frequency while the changing layer conditions caused a
transition of the returned energy from the E to the upper layer, or vice
versa. The results are in direct contrast to the observations illustrated
by Schafer and Goodall which were obtained under similar conditions
but at a latitude of about 40° north.

Figure 14 illustrates a continuous recording on 1500 kc during the
morning of May 30, 1934. It is seen that, at the beginning of the run,
the returned echoes from the E-layer were strong and those from the
F-region were weak. Practically all the reflected energy was therefore
penetrating the E-region. As the morning progressed, the echo energy
at the F-region grew greater and the intensities of the echo energy
corresponding to the E-echoes grew stronger and the F-echoes grew
weaker. By 7h 30m the intensity of the E-echoes was about equal to
that from the upper region. By 7h 45m the E-echoes were definitely
stronger than the F-echoes and by 8h 00m the returned F-echoes
were sufficiently strong showing that practically all the reflected
energy was then being returned from the E-region.

Figure 15 illustrates a continuous recording on 1500 kc during the
afternoon of May 30, 1934. Recombination is then setting in, causing
a transition of the returned energy from the E-layer to the F-layer. Con-
sequently, the phenomena observed are time progressed were the reverse
of those indicated in Figure 14. At 16h 00m all of the reflected energy
was being returned from the E-region. By 16h 15m energy made additional
echo was observed at a virtual height of 200 km. By 16h 30m the in-
tensity of the upper echo had increased so that it was more than that from
the E-region, and its virtual height had fallen to 190 km. By 16h 50m
the negative intensities indicated that the greater portion of the reflected
energy was penetrating the E-region and was being returned from the
upper or F-layer.

Figures 14 and 15 illustrate similar series of observations on 1750 kc
for the times indicated. The general character of the transition is the
same as has been described previously.

The reflections from the F-region can be distinguished from the
regular reflections of the E-region because of the fact that while the
virtual height of the E-layer reflection is relatively constant the virtual
height of the F-region reflections is found to vary as illustrated. Figure 4
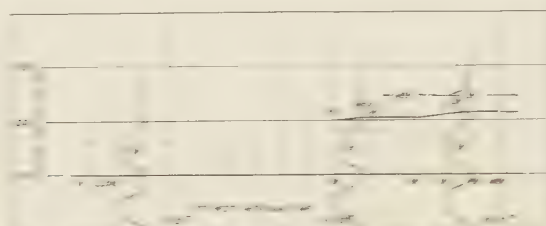
is a record of a continuous recording made April 6, 1934, on a frequency of 2800 kc. The transition is typical and the illustrated echo-patterns also indicate the manner with which the echoes from the F_1-layer gradually build up.
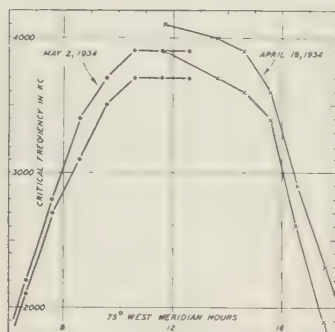

FIG. 5—DIURNAL VARIATION OF E-LAYER CRITICAL-FREQUENCY LIMITS

Figure 5 illustrates the diurnal characteristic of the maximum ionization of the E-layer as reduced from the results of separate runs two weeks apart. The lower limit indicates that frequency at which the intensity of the echoes from the E-region is slightly greater than that of the echoes from the F_1-layer, while the upper limit indicates that frequency at which the echoes from the upper layer are the stronger. These limits are only relative but do indicate, to a certain extent, the nature of the diurnal variation of the maximum ionization in the E-region.

It should be noted that as the frequency is increased to values several thousand kilocycles above the transition-frequency, E-layer reflections diminish to very small magnitudes, but can usually be found, if sufficient receiver-sensitivity is used having the relatively unchanging virtual height of about 100 km. These reflections appear to be of the same nature as those reported by Gilliland, Kenrick, and Norton[9] and by Kirby, Berkner, and Stuart.[8]

DISCUSSION AND CONCLUSIONS

The most characteristic feature of the E-layer investigations at Huancayo has been shown to be the lack of a definite critical-frequency, such as usually described by the accompanying long retardations, and the distinct jump of the virtual height of the major reflections from the level of the E-layer to that of the F-layer. This prevailing condition, for a typical investigation where the frequency is increased from a value below the transition-frequency, may be reviewed as follows:

(1) There is no evident change in the virtual height of the echoes from the E-region.
(2) There is only a gradual diminution in the intensity of the E-echoes.

[9]Bur. Stan. J. Res., 7, 1083-1104 (1932).

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(3) Partial penetration of the E-layer is indicated by the appearance of weak echoes from an upper ionized layer.

(4) The intensity of the echoes from the upper layer gradually becomes greater with little or no change in the virtual heights.

(5) Small echoes are received from the E-layer at frequencies several thousand kilocycles above the transition-frequency, where the major portion of the reflected energy is returned from upper layers which can be definitely identified.

Since the group- or signal-velocity is the factor which determines the length of time required for a signal to travel to an upper ionized layer and back, [10] the absence of any appreciable retardations during the transition from the E-layer to the F-layer indicates that the conditions necessary to cause very low group-velocities over a considerable distance do not exist. For the higher latitudes, where the E-critical-frequency is characterized by long retardations, the approximate formula for the group-velocity[10]

$$V_g \doteq nc$$

where n is index of refraction and c is 3×10^{10} cm per sec, has been used to explain the great retardations. This approximation, however, is based upon the assumption that dissipation depending upon the ratio of collision-frequency to transmitted frequency is negligible. It is evident that if n is complex, this approximation is not easily applicable. Epstein[11] has shown that if the collisional frequency is large, part of the energy will be reflected and part transmitted in much the same manner as observed. It may be noted that this appears to be the necessary condition for the qualitative fulfilment of what may be termed the "atmospheric-dynamo" theory of diurnal variation of the Earth's magnetic field. This theory requires a comparatively high conductivity of the upper atmosphere in the equatorial regions to permit the closure of the atmospheric currents across the Earth's magnetic field. Further experiments are necessary to determine the quantitative sufficiency of this condition.

Similar investigations in other equatorial regions, as well as a survey running through the equatorial regions from the higher latitudes, should supply valuable additional information as to the world-wide nature of the ionosphere, with its effect upon magnetic phenomena and radio transmission, and as to the physical composition of the upper atmosphere.

[10] Pedersen, The propagation of radio waves, Chapter 10.
[11] P. S. Epstein, Proc. Nation. Acad. Sci., **16**, 37-45 and 627-663 (1930).

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F-REGION IONOSPHERE-INVESTIGATIONS AT LOW LATITUDES

By L. V. Berkner and H. W. Wells

Abstract—Further studies of the *F*-region, ordinarily composed of the *F*-layer at night which separates into the F_1- and F_2-layers at small zenith-angles of the Sun, have been continued at the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Instituticn of Washington during the past year. The separation of the F_1- and F_2-layers appears to occur because of a decrease of virtual height of the F_1-layer and a marked rise of virtual height of the F_2-layer. To adequately represent this effect, iso-ionic charts showing the change of virtual height and ionization with time have been constructed. This construction is made possible by a convenient simplification of the virtual height versus frequency graphs obtained from the observed data.

An examination of the characteristics of the F_1-layer shows little change of maximum ionization or lowest virtual height for any particular time from day to day. Such changes rarely exceed ±5 per cent. On July 30, 1934, a major magnetic disturbance coincided with a reduction of 15 per cent in noon maximum F_1-layer ionization, indicating a relation of this layer to terrestrial-magnetic effects. The character of the F_1 critical-frequency is found to change from day to day, indicating differences in the "degree of separation" at a particular point. Further information is necessary to the interpretation of this effect. The iso-ionic charts for various zenith-angles during the day are compared with the results for corresponding zenith-angles at Washington. Good agreement is found and makes possible an estimate of geographical distribution. This is represented by a three-dimensional iso-ionic chart. The single *F*-layer existing at large zenith-angles and at night is found to decrease in maximum ion-content on an average during the night, and to begin a rapid increase in maximum ionization before sunrise on the ground but after sunrise at the height of maximum ionization. It is shown that the solar rays active in ionizing the *F*-layer must be therefore filtered out in the lower atmosphere, and the lower limit of this effect is estimated from the data.

The character of the variations of maximum ionization and minimum virtual-heights of the F_2-layer varies greatly from day to day at any particular time as contrasted to the comparatively regular characteristics of the lower layers. No typical curves can be shown, but averages of the F_2 critical-frequency for periods including small changes in noon zenith-angle indicate that on an average a minor maximum occurs in the morning, a minimum occurs near noon, and a major maximum occurs in the afternoon, followed by a decrease at night. Individual variations from the average are described. It is found that the F_2 critical-frequencies are on an average greatest during the southern solstice. The effects are compared to the published data for Washington where the noon values of F_2 critical-frequency are found to vary in the same manner. This fact introduces a new complication into an already complex problem.

The "scattered reflections" reported by other observers above 600 km are apparent at Huancayo. There is also frequently apparent a hitherto undescribed reflection from layers in the *F*-region having a small magnitude decreasing with frequency and a virtual height nearly unchanging with frequency and approximating the lowest virtual height of the *F*-layer involved. Additional stratification of the *F*-region is occasionally observed.
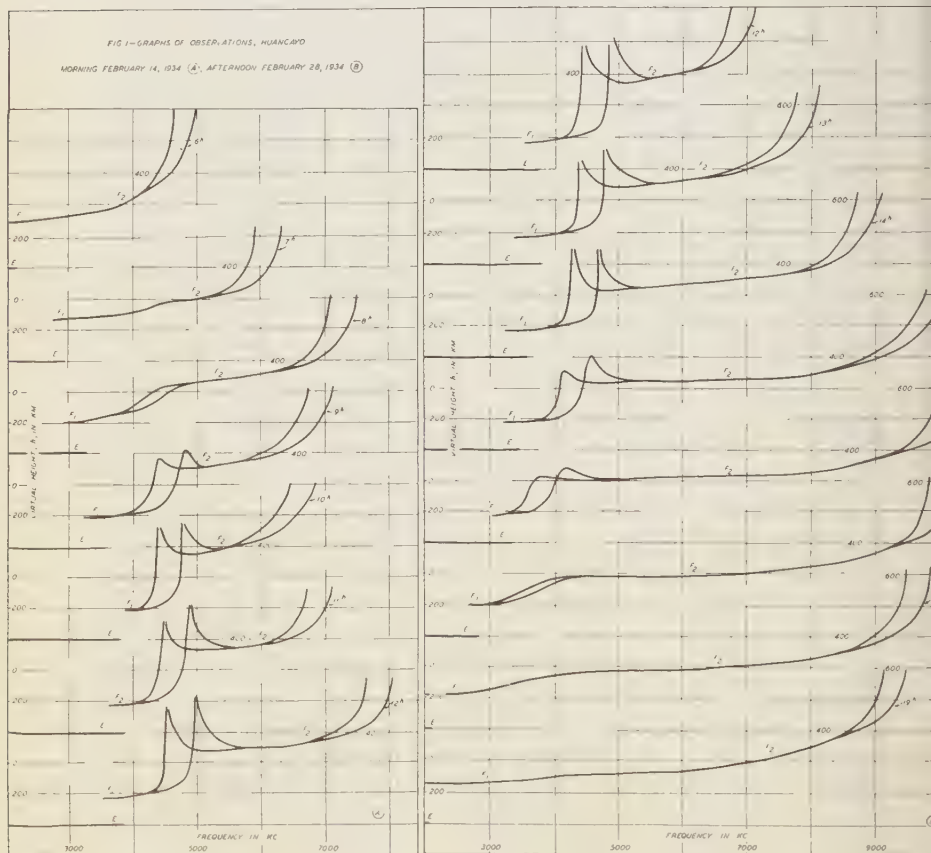
It is apparent that extensive data are required to effect a more complete understanding of these phenomena, and an automatic multi-frequency technique is desirable. It is suggested that a systematic simplification of data, such as described, and the construction of iso-ionic graphs would lead to an effective and simple representation of such data.

I—Character of data

The accumulation of new and more extensive data by radio methods at a number of locations throughout the world is serving to clarify certain of the earlier ideas concerning the structure of the ionosphere and to introduce new problems which greatly enhance the research which can be accomplished by such methods. As is often the case in such research, factors of importance, unforeseen on the basis of the early hypotheses, are becoming evident. When put in their proper order, they will extend the understanding of the problem beyond the limits earlier believed possible. This is particularly true of the region of the ionosphere above about 175 km, known as the *F*-region.

The problems of this study essentially involve the determination of the conformation of a three-dimensional figure having, as dimensions, ionization, virtual height, and time in which the ionization and virtual height change with time from day to day. This figure is approximately repeated at daily intervals within certain limits depending upon seasonal, secular, and other factors at present unknown. Determination of this figure is accomplished by obtaining a series of sections of the figure at regular intervals in two ways: (1) The virtual height may be continuously recorded on a number of frequencies as time progresses; (2) the frequency may be varied throughout the required range at regular intervals, and the virtual height recorded for each frequency.

The latter method has been found preferable because the results may be more fully interpreted. It has been in use in these investigations for a number of years. The frequency may be varied, step by step, manually, or the technique of automatic multi-frequency recording, recently demon-

FIG. 1—GRAPHS OF OBSERVATIONS, HUANCAYO

MORNING FEBRUARY 14, 1934 (Ⓐ); AFTERNOON FEBRUARY 28, 1934 (Ⓑ)

strated by Gilliland, may be used to obtain this information much more completely and comprehensively.

The manual multi-frequency method, described completely elsewhere [see reference 1 at end of paper], has been used at the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, since April, 1933. This Observatory is in Peru in latitude 12° 02'.7 south and longitude 75° 20'.4 west at an elevation above sea-level of 11,000 feet. Upon the completion of earlier experiments, a program of regular measurements was initiated. This program included the systematic observation of the changes of ionization of the *F*-region.

Observations for typical February days are shown in Figure 1. Figure 1*A* illustrates data obtained for the morning of February 14, 1934, while Figure 1*B* illustrates similar data for the afternoon of February 28, 1934. The data shown for the *E*- and F_1-layers are taken from the hourly averages of observations during the month of February. It will be demonstrated later that this is not essentially different from the data for an individual day. The interpretation of such records has been described in earlier papers in some detail [1, 2, 3, 4]. Portions of the graphs in which virtual height varies slowly and quite uniformly with frequency are interpreted as strata of the ionosphere in which the ionization increases rapidly with respect to height, the most important strata being designated by the symbols *E*, F_1, and F_2 as shown. As the frequency is increased the penetrating power of the wave in the ionized medium is also increased so that each stratum is penetrated as a certain frequency, determined by the maximum ionization of that stratum, is reached. Near this penetrating, or "critical," frequency rapid changes in virtual height, often accompanied by long retardation or discontinuity of the reflection-pattern (as plotted), are frequently observed. In these regions the ray is split into two components due to magneto-ionic double refraction. This occurs because the index of refraction of the medium is different for the transverse and longitudinal components of the wave with respect to the Earth's magnetic field [1, 4, 5, 6]. The ionization corresponding to a particular virtual height at normal incidence for the ordinary ray may be calculated from the well-known expression

$$N = (\pi f^2/e^2 \, (1 - a)$$

where N is the ionization in equivalent numbers of electrons, f is the frequency, m is the mass of the electron of charge e, and a is the constant used by Lorentz to account for local polarization in the medium. Putting $a = 0$ this expression reduces to

$$N = 1.24 \, f^2 \times 10^{-8}$$

which is the value used for calculations in this paper [7, 8, 9, 10, 11].

II.—SEPARATION OF THE *F*-REGION INTO TWO STRATA

It has been pointed out in earlier publications that when the zenith-angle of the Sun is small, the *F*-region is found to separate into two strata, the F_1- and the F_2-layers [1, 4]. In considering the variation of ionization with virtual height and time, particularly in connection with the further study of this separation, it is convenient to simplify the

observed virtual-height versus frequency curves to make possible the construction of iso-ionic charts. It is known that the virtual height measured is not only dependent upon the time required for the wave to travel to the reflecting layer and return, but also upon the reduction in group-velocity experienced while passing through such a dispersive medium. It has been shown that this effect is small if the wave penetrates only to a region where the ion-gradient is high or increasing [12, 13, 14, 15, 16]. As the transmitted frequency approaches the critical frequency for the layer, the dielectric constant is low and the ion-gradient is decreasing slowly to zero with respect to height, so that the wave is propagated with low group-velocity for a considerable distance. The reflection is thus subject to an additional retardation [12, 13, 14, 15, 16]. This additional retardation cannot be easily calculated in the absence of exact knowledge of the ion-distribution. However, it is found in the frequency-bands between critical frequencies that the virtual height falls rapidly to values which change slowly over wide ranges of frequency, and in which magneto-ionic splitting is not apparent. In these bands the virtual heights are apparently not greatly affected by the lower layers and therefore the gradient must be high. In any simplification it is deemed desirable to leave these portions of the curves unchanged. They are indicated by solid lines in the simplified curves.

Near the critical frequencies the effect of low group-velocities is very great. It is therefore convenient for the purpose of simplification to estimate values of virtual height. These estimates are based upon arbitrary rules reached through a consideration of the limits imposed by the flatter portions of the curves, by the form of the critical-frequency curves and their change with time, and by knowledge of the effect of ion-distribution upon the observed increase in group-retardation. Such estimates are indicated in the simplified curves by broken lines from the frequency at which splitting begins to the critical frequency, and by dash-dot lines from the critical frequency to the frequency of the lowest virtual
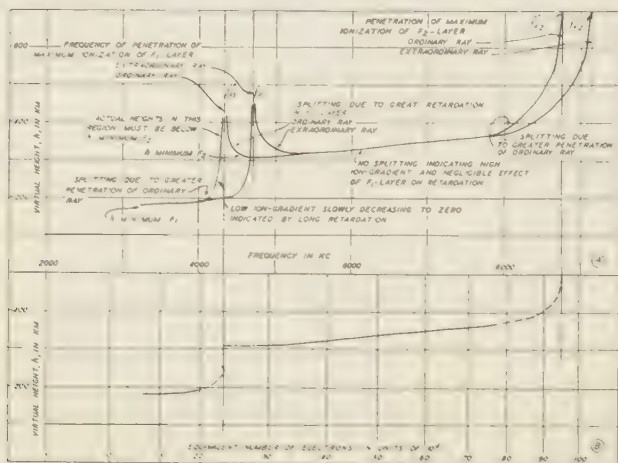

FIG. 2— ILLUSTRATION OF OBSERVED VIRTUAL-HEIGHT VERSUS FREQUENCY GRAPH (A) AND SIMPLIFIED VIRTUAL-HEIGHT VERSUS FREQUENCY GRAPH IN TERMS OF IONIZATION (B)

height of the next highest layer. In the case of the critical frequency of the F_2-layer the upper limit of virtual height of the simplified curves has been arbitrarily placed at 500 km. In this simplification the extraordinary ray is ignored except for the determination of the limits of splitting. No other essential data are lost.

Figure 2*A* illustrates the method of arriving at the simplified ionization-curve shown in Figure 2*B*. Application of this method to the data of Figure 1 results in the series of simplified virtual-height versus ionization curves shown in Figure 3. These simplifications make possible the
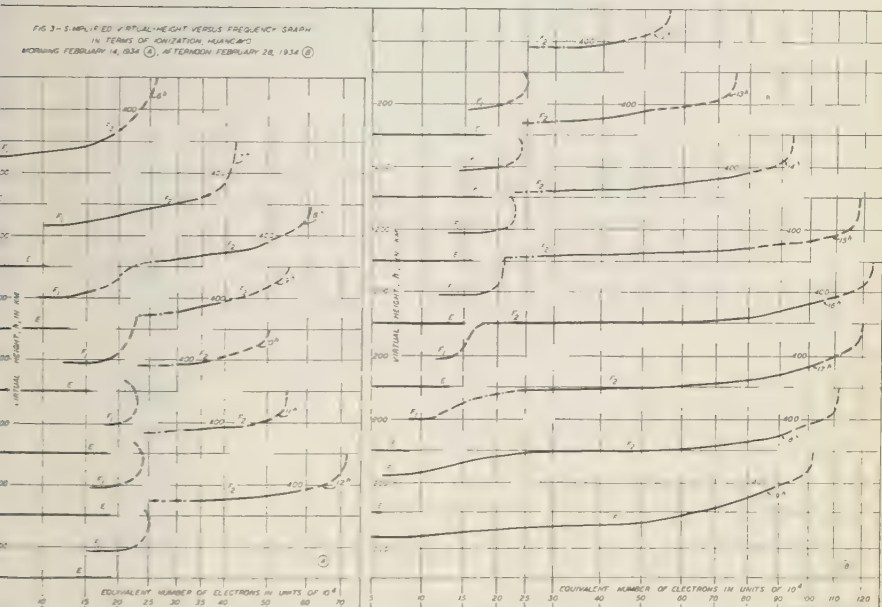
construction of iso-ionic charts of ionization versus virtual height and time as shown in Figure 4. Such charts show in much greater detail than heretofore possible the mechanism of the separating in the morning and the merging in the evening of the F_1- and F_2-layers. The separation is the result of both a decrease in the virtual height of the lower F-region ionization and of a marked rise in the virtual height of the upper F-region ionization.

III—CHARACTER OF THE F_1-LAYER

Before considering this separation further, the general characteristics of the F_1-layer will be discussed. It is found, as illustrated in Figure 1, that the first evidence of separation of the F_1-layer from the F-region appears as a bend in the virtual height versus frequency curve. This becomes progressively steeper with time and shows distinct evidence of splitting due to double refraction. As the Sun approaches the zenith this effect becomes distinctly a critical frequency [1, 4], which is found to
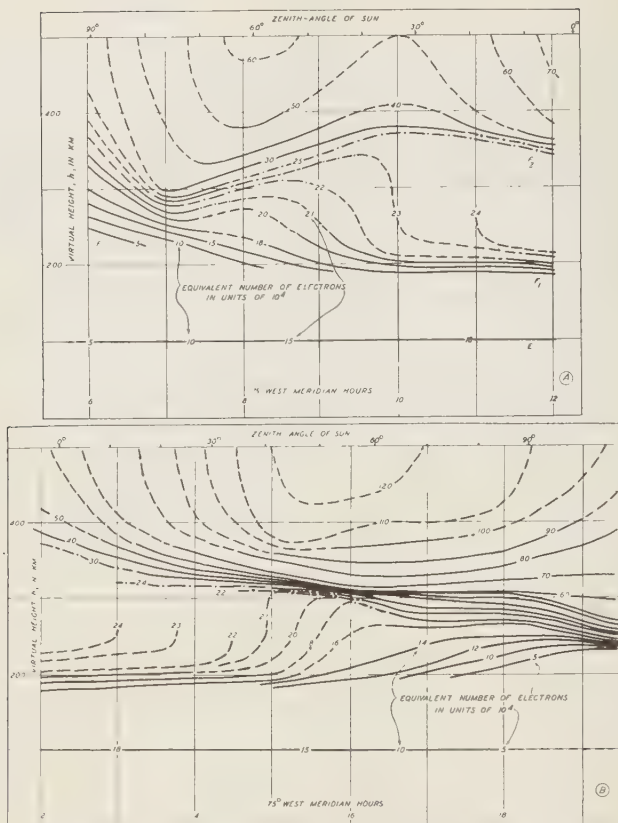
FIG 4 — ISO-IONIC CHART FROM SIMPLIFIED VIRTUAL-HEIGHT VERSUS IONIZATION GRAPHS, HUANCAYO
MORNING FEBRUARY 14, 1934 (A); AFTERNOON FEBRUARY 28, 1934 (B)

have a diurnal variation. It is desirable to take into account the bend ap-
pearing before the occurrence of the distinct critical-frequency, and for this
purpose the F_1 critical-frequencies have been classified into three types:
(1) A distinct critical-frequency accompanied by long retardations and
splitting due to double refraction; (2) less distinct than type (1), ac-
companied by retardations greater than the minimum retardation of the
next higher layer but without a discontinuity, and in which the doubly
refracted components are observed to distinctly cross; (3) a bend in the
virtual height versus frequency curve in which the retardations do not
become greater than those for the next higher layer and the doubly
refracted components, if present separately, are so close that their
crossing is not apparent. Critical frequencies of types (2) and (3) are
plotted from the limits confining the effect.

For the purpose of determining average values and variations from
the average, the year has been divided into a number of periods as
shown in Table 1.

TABLE 1—*Division of the year according to noon zenith-angle of the Sun at Huancayo*

Noon zenith-angle	Period	Date	Period	Date
− 5 to −11.5	1	Nov. 12 to Jan. 31		
− 5 to + 5	2	Feb. 1 to Feb. 28	2′	Oct. 12 to Nov. 12
+ 5 to +20	3	Mar. 1 to Apr. 9	3′	Sept. 5 to Oct. 11
+20 to +30	4	Apr. 10 to May 9	4′	Aug. 5 to Sep. 4
+30 to +36.5	5	May 10 to Aug. 4		

These are based upon the approximate zenith-angle of the Sun at noon.
Figure 5 shows the average values of F_1 critical-frequencies for the ordinary and extraordinary rays obtained from eight days of measure-
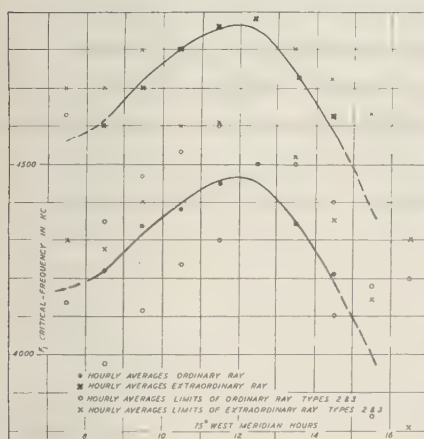

FIG 5—HOURLY AVERAGES, PERIOD 2, F_1 CRITICAL-FREQUENCY, HUANCAYO, FEBRUARY 1934
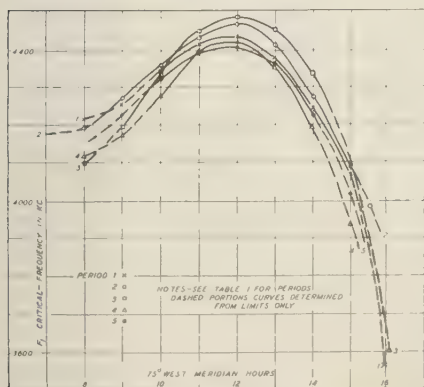
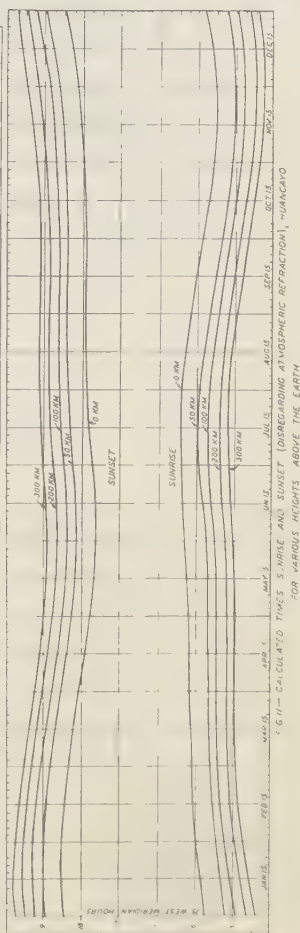FIG 6—HOURLY AVERAGES, PERIODS 1-5, F_1 CRITICAL-FREQUENCY HUANCAYO, 1933-1934

FIG 11—CALCULATED TIMES SUNRISE AND SUNSET (DISREGARDING ATMOSPHERIC REFRACTION), HUANCAYO FOR VARIOUS HEIGHTS ABOVE THE EARTH

ment during February 1934 (period 2) for each hour, together with the limits observed for the critical frequencies of types (2) and (3). Figure 6 shows the average diurnal characteristics of the F_1-layer compared for periods 1, 2, 3, 4, and 5, obtained in the manner illustrated in Figure 5. The hourly averages of the type-numbers are given in Table 2. Except in the early morning the maximum ionization of the F_1-layer is seen to

TABLE 2—*Average hourly type-number F_1 critical-frequency, Huancayo, 1933-34*

| Period	75° west meridian hour									
	$7-8$	$8-9$	$9-10$	$10-11$	$11-12$	$12-13$	$13-14$	$14-15$	$15-16$	$16-17$
1	3.0	2.0	1.0	1.0	1.0	1.0	1.0	1.2	2.6	3.0
2	3.0	1.8	1.3	1.4	1.1	1.0	1.2	1.7	2.0	3.0
3	3.0	2.6	2.0	1.8	1.8	1.6	2.0	2.1	2.6	3.0
4	3.0	2.0	1.8	1.5	1.7	1.6	1.6	2.0	2.5	3.0
5	3.0	2.3	2.3	1.2	1.3	1.6	1.6	2.2	2.6	3.0

rise toward noon, becoming very flat about noon, and to decrease in the afternoon as some function of the zenith-angle of the Sun in a manner similar to the normal variation of the E-layer ionization, shown in earlier publications [4]. In the early morning $(7^h\ 00^m$ to $8^h\ 30^m$ in Fig. 4) there is little change in the value of maximum ionization in the region of the F_1-layer, although the virtual height of the maximum ionization is decreasing. This is illustrated by the flatness of the iso-ionic curves at this time, and is, apparently, directly the result of the phenomenon of separation.

A comparison of the day-to-day values of maximum ionization of the F_1-layer with the average values show that during a particular period there is very little variation at any given time on normal days it does not exceed about ± 5 per cent. So small a variation indicates a great homogeneity of this region under ordinary conditions. The noon maxima of F_1-layer ionization are plotted in Figure 7 for the period of observation. As might be expected from the flatness of the diurnal characteristic at noon, the seasonal variation of the noon maximum is so small as to be masked by day-to-day variations. Seasonal effect becomes apparent during the late afternoon in the diurnal averages of Figure 6 because of the changing time of sunset.

A notable exception to this small variation in the maximum F_1 critical-frequency occurred on July 30, 1934. This is shown in Figure 7. On this day the maximum ionization was about 15 per cent below the average for the period. A major magnetic disturbance taking place on this date was the first during the period of the observations. There can be little doubt that the effects were related but unfortunately extended runs on this date including data for the entire ionosphere were not made.

The lowest virtual height of the F_1-layer at noon varies little from day to day, nor does it vary much with season. This can be predicted from the flatness of the iso-ionic curves for this layer during several hours near midday. A plot of the hourly average values of the lowest virtual heights observed for the F_1- and F_2-layers is shown in Figure 8.

The characteristics of the F_1-layer so far discussed are all marked for their small day-to-day variations. Contrasted to these effects the character of the virtual height versus frequency curves at the F_1 critical-
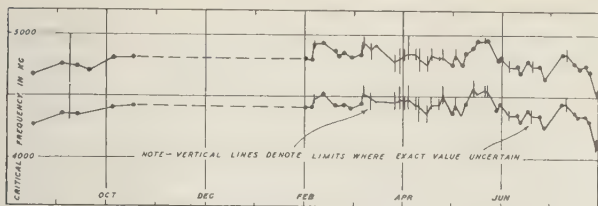
FIG. 7—DAILY MAXIMA F_1 CRITICAL-FREQUENCY, HUANCAYO, AUGUST 1933 TO AUGUST 1934
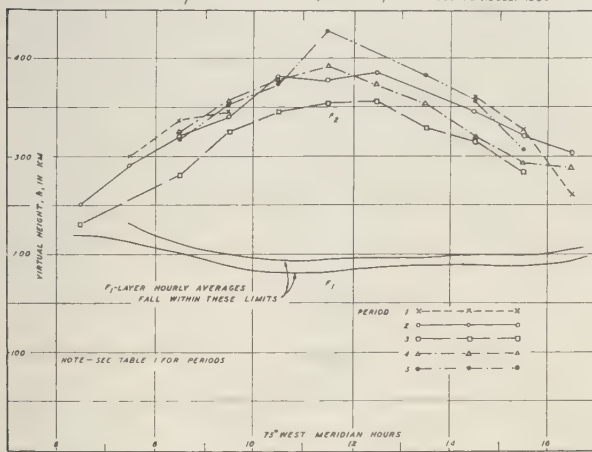
FIG. 8—HOURLY AVERAGES, PERIODS 1 TO 5, VIRTUAL HEIGHTS F_1- AND F_2- LAYERS, HUANCAYO

frequency for a particular time is found to vary considerably from day to day. On some days the type of critical frequency is found to change rapidly from type (3) through type (2) to type (1), remaining characteristically type (1) throughout most of the day and only returning to type (3) late in the afternoon. On other days the character will change slowly from type (3) to type (2), only reaching type (1) for a short time at noon and returning slowly to type (3) during the afternoon. On a few days the times during which critical frequencies of type (1) exist do not center about noon but occur somewhat before or after noon. The average type-numbers for the different periods, shown in Table 2, demonstrate that critical frequencies of type (1) occur most frequently with small zenith-angles of the Sun and that on an average there is a definite seasonal progression toward type (3) as the zenith-angle of the Sun becomes greater. These facts show that the ion-density and the ion-distribution between the F_1- and F_2-layers, shown in part by the dashed lines of Figure 4, change from day to day. What may be termed "the degree of separation" of the layers is quite different from day to day, increasing only on an average as the zenith-angle of the Sun becomes small. It may be estimated from the available data that generally critical frequencies of type (1) appear for the F_1-layer when the zenith-angle of the Sun is about 35°, although this may vary as much as ±15° from day to day.

The regularity of the maximum ionization and virtual-height characteristics of this layer make it reasonable to assume that the portion of

the iso-ionic curves of Figure 4 referring to the F_1-layer can also be considered approximately as the ion-distribution along the 12th parallel of latitude for this date. To obtain a further idea of the geographical distribution of this layer it is of interest to refer to the evidence obtained at Washington by Kirby, Berkner, and Stuart [4]. The maximum F_1 critical-frequency of 4500 kc, reported for summer noon at Washington (zenith-angle about 14°), corresponds very closely to the results given for Huancayo in Figure 7. This provides a powerful argument in view of the flatness of the diurnal characteristic at noon that the north-south distribution of ionization must be similar to the distribution along a parallel for equal zenith-angles. As the zenith-angle of the Sun increases with season to about 60° at Washington, the curves and description of the magnitude and character of the F_1 critical-frequency on the average agree quite well with the iso-ionic chart of Figure 4 for correspondingly greater zenith-angles of the Sun. It seems probable, therefore, that iso-ionic curves for the F_1-layer drawn along the meridian from a point directly under the Sun (that is perpendicular to Fig. 4 at 12^h 15^m) would appear approximately similar to Figure 4B, at least up to about 60° (17^h). On this basis Figure 9 gives the best conception of the geographical distribution of this layer that can be obtained from available data.
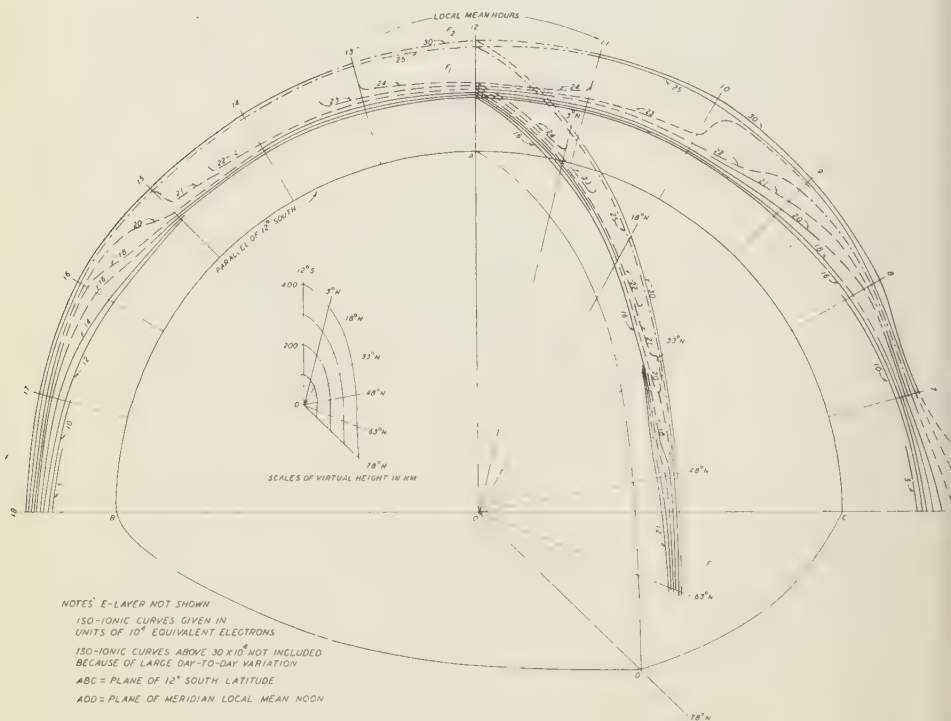

FIG 9— SKETCH SHOWING PROBABLE GEOGRAPHIC DISTRIBUTION F_1-LAYER (DATA 1931-1934) FOR SUN'S DECLINATION 12° SOUTH

Figure 9 is drawn for the F_1- and lower F_2-layers with the east-west ion-distribution along the plane of the parallel of 12° south so that the data of Figure 4 for zero noon zenith-angle can be used in determining the distribution. A meridian, representing the local mean noon meridian, is drawn perpendicular to this parallel, meeting it at the point of zero noon zenith-angle. In order to preserve perspective of the figure, the virtual heights along the meridian have been foreshortened as shown in the accompanying scale by the ratio of the projection of a radius to the respective latitudes to the full radius. The scale of the radius of the Earth is naturally much smaller than the scale of heights to permit this to be reproduced in some detail.

This evidence may be roughly summarized by saying that the F_1-layer appears to be an approximately circular area of ionization under the Sun, somewhat depressed below the level of the surrounding F-layer and merging upward into this single F-layer where the zenith-angle of the Sun is large. This layer, in effect, appears to remain under the Sun as the Earth rotates, and to move to the north or south with respect to the Earth's surface as the equator tilts south or north with changing declination. Such a distribution accounts for the seasonal changes observed.

The character of the critical frequency at any point from day to day is important to this conception. It is desirable to know if the day-to-day variation of the type of critical frequency at a point under the Sun is typical of the entire central area. Such a condition would indicate a major change of structure between the F_1- and F_2-layers from day to day. On the other hand, large differences of character from point to point would determine whether there may be a shift in the entire area from day to day, or whether the structure of the region between the layers may be subject to local disturbances and distortions. This study can only be accomplished by the coordinated effort of a number of investigators by means of some automatic-registration technique. As there is evidence that the changes in this region are correlated with magnetic disturbances, such an investigation is of particular interest.

IV—CHARACTER OF THE F-LAYER

It is apparent from Figures 4 and 9 that at large zenith-angles of the Sun, and after sunset, the F-region appears as a single F-layer. The lowest virtual height of this layer ranges between 220 and 270 km for the observations so far made at Huancayo. Extensive observations at night requiring runs through the entire frequency-spectrum returning reflections have been limited so that very little can be said concerning the variations at night of virtual heights of the iso-ionic contours. On an average the critical frequency decreases during the night until a short time before sunrise, but from night to night there may be a difference of as much as 2000 kc at a particular time and occasionally temporary rises in the critical frequency are such as are shown in Figure 10. Sufficient observations are not available to determine if night-increases in critical frequency have any regular distribution. Before dawn the critical frequency ordinarily reaches its lowest value, usually lying in the frequency-range 1500 to 3000 kc. The decrease before dawn is followed by a sudden and quite uniform rise of several thousand kilocycles in critical
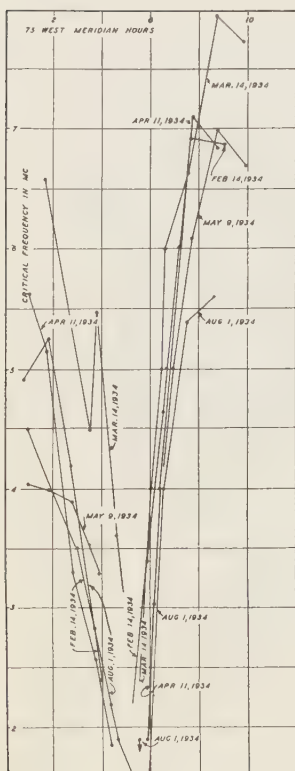
FIG. 10—EXAMPLE VARIATION F CRITICAL-FREQUENCY
HUANCAYO, DURING EARLY MORNING

frequency. The rise commences before sunrise on the ground at the point of observation and continues for two or three hours. This rise is illustrated for the ordinary ray in Figure 10. During this period the change is nearly linear with time. The time-rate of change of ionization is very high as compared with the corresponding change for the lower layers. Consider, for example, the data for August 1, 1934. The critical frequency is observed to decrease steadily to below 1700 kc (the limit of the observing equipment) until 5^h 30^m. Ionization must commence between 5^h 35^m and 5^h 55^m, and following this the critical frequency is observed to rise at the rate of about one kilocycle per second.

For the purpose of rough calculation we assume that the maximum ionization is located above 250 km. This assumption is justified by the fact that the virtual height versus ionization curve is nearly flat at this time, rising only slowly with no splitting of the ray apparent up to 250 km. Referring to Figure 11, it is found that, although sunrise at 250 km has taken place before 5^h 15^m, the critical frequency has continued to decrease. The limiting times of 5^h 35^m to 5^h 55^m, within which the rise in ionization begins, correspond to sunrise at 125 km and 60 km, respectively. Therefore, appreciable ionization only begins when the Sun's rays pass above a certain level in the atmosphere, the rays active in ionizing the F-region being entirely filtered out in passing through atmosphere. If, below this level and at a certain time, sunrise occurs at a height h above a point on the dark side of the Earth, it can be shown that, to a first approximation, the Sun's rays reaching a point y above the same point at the same time will be tangent to an imaginary shell of distance k above the Earth, according to the relation [17] $k = (y - h)$.

Putting $y = 250$ km and h ranging from 60 to 125 km, we have k ranging from 125 to 190 km. This is the lower limit of height above the Earth at which the component of radiation of the Sun which is active in ionizing the F-region can penetrate the Earth's atmosphere when directed parallel to the Earth's surface. It may be pointed out conversely that, if the penetration of this ionizing radiation can be determined on the basis of other considerations, information concerning the actual height of the maximum ionization can be obtained.

V—CHARACTER OF THE F_2-LAYER

Following the steep uniform rise in the F-layer ionization a definite break occurs in the curve and then a slower rise—a flattening out or a decrease in the critical frequency. The break coincides approximately with the appearance of indications of the separation of the F_1- and F_2-layers, illustrated in Figure 4 at about 8[h]: The continuation of the F critical-frequency after the commencement of this separation is here considered with the phenomena of the F_2-layer. Contrasted with the relatively uniform characteristics of the lower layers with regard to virtual heights and critical frequencies, the behavior of the F_2-layer is erratic. There is no diurnal characteristic of the F_2 critical-frequency which may be considered "normal" for any period at Huancayo [1]. There are, however, certain apparent trends which will be discussed.

Most frequently the rapid morning rise to a maximum critical-frequency is followed by a decrease, which reaches a minimum near and usually before noon. A rise to a higher maximum in the afternoon follows with a decrease beginning near sunset. Occasionally the morning
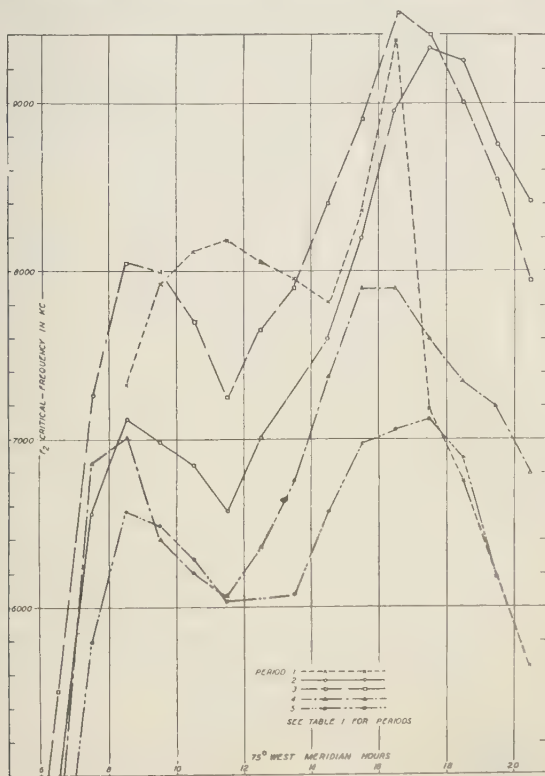
FIG. 12 — HOURLY AVERAGES, PERIODS 1—5, F_2 CRITICAL-FREQUENCY, HUANCAYO, 1933–1934

maximum is greater than the afternoon maximum, and sometimes the noon minimum is entirely replaced by a single maximum for the day. The hourly averages for the F_2 critical-frequency for the periods outlined in Table 1 are plotted in Figure 12. In referring to this Figure it must be remembered that the actual critical frequency at any particular time from day to day may vary as much as 1500 kc. It can be seen that on the average a minor maximum occurs in the morning, a minimum before noon, and a major maximum in the afternoon, during the periods of observation. It is also apparent that generally the F_2 critical-frequencies were much higher during the southern solstice than during the northern solstice.

Referring to Figure 8, it is seen that on an average the virtual height of the F_2-layer rises, following the separation, until the Sun reaches the smallest zenith-angle and then decreases until the F_1- and F_2-layers merge. The time of maxmium virtual-height on any particular day may occur at a time earlier or later than noon as, for example, in Figure 4A. There also appears to be a distinct tendency for the virtual height of the F_2-layer to be lower when the critical frequency is high, but other phenomena affecting the virtual height make a definite conclusion in this respect hazardous until runs throughout the day become available.

It has been observed at Washington [4, 18, 19] that in the winter (noon zenith-angle approaching 60°) the F_2 critical-frequency reaches a single daytime maxmium. As the season progresses the value of critical frequency at noon has been observed to decrease, the maximum occurring later in the afternoon and a minor maximum in the morning. In the summer (noon zenith-angle approaching about 15°) a minimum has been observed near noon with the major maximum in the evening. This condition in summer at Washington differs in two major respects from the observations at Huancayo for corresponding zenith-angles: (1) The highest values of midday critical-frequency are observed at both Washington and Huancayo during the southern solstice and the lowest midday values are observed during the northern solstice, even though the two stations are in different hemispheres; (2) the evening maximum at Washington during the northern solstice occurs from two to four hours later than the afternoon maximum at Huancayo during the three periods in which roughly corresponding conditions of noon zenith-angles exist.

The latter difference may be at least partially explained by the fact that, for small zenith-angles, the period of sunlight is three to four hours longer at Washington than at Huancayo because of the difference of latitude. The first difference is not so easily understood. One contributing factor may be the fact that the Earth is about two and one-half per cent nearer the Sun in its elliptical orbit during the southern solstice than during the northern solstice. Thus the intensity of the received radiation is about five per cent greater at this time. The major factor is probably closely related to the cause of the midday decrease in critical frequency at small noon zenith-angles and the separation of the F-region into two layers, phenomena which are not simply explained. Data from Huancayo together with the published data of the National Bureau of Standards [4, 18, 19], as extended by the Ursigram data, leaves little doubt that in general change in the time of maximum and resulting change in midday critical-frequency must be a seasonal effect. It therefore seems difficult to form a conception of geographical distribution of the F_2-layer compat-

ible with all of the facts on the basis of the present data. It is apparent, however, that the variations of this layer are quite complex and that additional and more complete data, particularly from the south temperate zone, together with determinations of purely local effects, must be made available before the situation can be clarified. Data from the Watheroo Magnetic Observatory of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, at which equipment is now being placed in operation, should aid materially.

VI—OTHER *F*-REGION EFFECTS

(1) It has been found occasionally that during the hours of daylight additional stratification of the *F*-region occurs. Additional critical frequencies are observed to "grow" in the F_2-layer virtual-height versus frequency graphs for a few hours and then to disappear, particularly near the southern solstice, when the F_2 critical-frequency is lowest. It is impossible to decide, on the basis of existing data, whether these effects are due to an upper stratum which is uncovered by the receding ionization of the F_2-layer, whether the effect is due to a non-homogeneous horizontal distribution or "cloudiness" of the F_2-layer, or whether the effect is due to the appearance of a new ion-bank above the F_2-layer for a temporary period [4]. These strata are marked by the same types of critical frequencies with magneto-ionic double refraction as are observed for the F_1- and F_2-layers.

(2) There is frequently observed a type of *F*-layer reflection not heretofore reported at other stations. This type of reflection first appears as the critical frequency of a lower layer is passed. It is of smaller magnitude than the main reflections from the next higher layer. The virtual height is about the same as the lowest virtual height of the main reflections from this layer. These reflections do not change appreciably in virtual height as the frequency is increased, although the main reflections are observed to pass through the critical frequency for the layer. The magnitude of this type of reflection decreases slowly as the frequency is increased, gradually disappearing without reaching a critical frequency. It seems probable that such reflections are due to a high ion-gradient near the lower part of the layer such as are discussed by Gilliland, Kenrick, and Norton [16] for the *E*-layer. When such reflections occur, they persist for only a few hours.

(3) Scattered reflections of the type discussed by Kirby, Berkner, and Stuart [4] are regularly observed at Huancayo. These reflections range upward from about 600 km. depending upon the frequency and the time of day, and are first observed at frequencies somewhat below the F_2 critical-frequency. They increase slowly in virtual height and diminish in amplitude as the frequency is increased so that they can be observed on comparatively high frequencies. It seems probable that such reflections are of the type described by Taylor and Young [20], although this must be confirmed by directional measurements. A recently published account by Mimno [21] of apparently the same type of reflections observed on a single frequency attributes such reflections to a *G*- and *H*-layer. In our opinion, however, because of the greatly different character of these reflections from that observed for the well-established layers, a decision in this matter must await more conclusive experimental evidence.

8

VII—Reduction of records

It has become apparent during the development of these investigations that a large number of observations are necessary to systematic and conclusive investigation of the ionosphere. The continuous automatic recording technique of Gilliland [19] immediately suggests itself as the logical method of obtaining such information. The quantity of material collected by such a method appears at first sight to be quite staggering from the standpoint of useful reduction and universal distribution. However, it appears possible to develop a comparatively simple and standardized technique of simplification and reduction of data to iso-ionic charts as illustrated in Figure 4. These charts contain in readily visible form practically all of the information concerning ion-density and comparative gradient, virtual heights, and time, excepting only the information concerning magneto-ionic double refraction. Such a reduction lends itself to ready classification and comparison of the observed data and will be extremely useful in the further development and exchange of evidence.

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OBSERVED RELATIVE SUNSPOT-NUMBERS, 1749-1933

EIDGENÖSSISCHE STERNWARTE IN ZÜRICH

TABLE 1—*Final relative sunspot-numbers, whole disc*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1749	58.0	62.6	70.0	55.7	85.0	83.5	94.8	66.3	75.9	75.5	158.6	85.2	80.9
1750	73.3	75.9	89.2	88.3	90.0	100.0	85.4	103.0	91.2	65.7	63.3	75.4	**83 4**
1751	70.0	43.5	45.3	56.4	60.7	50.7	66.3	59.8	23.5	23.2	28.5	44.0	47.7
1752	35.0	50.0	71.0	59.3	59.7	39.6	78.4	29.3	27.1	46.6	37.6	40.0	47.8
1753	44.0	32.0	45.7	38.0	36.0	31.7	22.0	39.0	28.0	25.0	20.0	6.7	30.7
1754	0.0	3.0	1.7	13.7	20.7	26.7	18.8	12.3	8.2	24.1	13.2	4.2	12.2
1755	10.2	11 2	6.8	6.5	0.0	0.0	8.6	3.2	17.8	23.7	6.8	20.0	9.6
1756	12.5	7.1	5.4	9.4	12.5	12.9	3.6	6.4	11.8	14.3	17.0	9.4	10.2
1757	14.1	21.2	26.2	30.0	38.1	12.8	25.0	51.3	39.7	32.5	64.7	33.5	32.4
1758	37.6	52.0	49.0	72.3	46.4	45.0	44.0	38.7	62.5	37.7	43.0	43.0	47.6
1759	48.3	44.0	46.8	47.0	49.0	50.0	51.0	71.3	77.2	59.7	46.3	57.0	54.0
1760	67.3	59.5	74.7	58.3	72.0	48.3	66.0	75.6	61.3	50.6	59.7	61.0	62.9
1761	70.0	91.0	80.7	71.7	107.2	99.3	94.1	91.1	100.7	88.7	89.7	46.0	**85.9**
1762	43.8	72.8	45.7	60.2	39.9	77.1	33.8	67.7	68.5	69.3	77.8	77.2	61.2
1763	56.5	31.9	34.2	32.9	32.7	35.8	54.2	26.5	68.1	46.3	60.9	61 4	45.1
1764	59.7	59.7	40.2	34.4	44.3	30.0	30.0	30.0	28.2	28.0	26.0	25.7	36.4
1765	24.0	26.0	25.0	22.0	20.2	20.0	27.0	29.7	16.0	14.0	14.0	13.0	20.9
1766	12.0	11.0	36.6	6.0	26.8	3.0	3.3	4.0	4.3	5.0	5.7	19.2	11.4
1767	27.4	30.0	43.0	32.9	29.8	33.3	21.9	40.8	42.7	44.1	54.7	53.3	57.8
1768	53.5	66.1	46.3	42.7	77.7	77.4	52.6	66.8	74.8	77.8	90.6	111.8	69.8
1769	73.9	64.2	64.3	96.7	73.6	94.4	118.6	120.3	148.8	158.2	148.1	112.0	**106.1**
1770	104.0	142.5	80.1	51.0	70.1	83.3	109.8	126.3	104.4	103.6	132.2	102.3	100.8
1771	36.0	46.2	46.7	64.9	152.7	119.5	67.7	58.5	101.4	90.0	99.7	95 7	81.6
1772	100.9	90.8	31.1	92.2	38.0	57.0	77.3	56.2	50.5	78.6	61.3	64 0	66.5
1773	54.6	29.0	51.2	32.9	41.1	28.4	27.7	12.7	29.3	26.3	40.9	43 0	34.8
1774	46.8	65.4	55.7	43.8	51.3	28.5	17.5	6.6	7.9	14.0	17.7	12.2	30 6
1775	4.4	0.0	11.6	11.2	3.9	12.3	1.0	7.9	3.2	5.6	15.1	7.9	7.0
1776	21.7	11.6	6.3	21.8	11.2	19.0	1.0	24.2	16.0	30.0	35.0	40 0	19 8
1777	45.0	36.5	39.0	95.5	80.3	80.7	95.0	112.0	116.2	106.5	146.0	157.3	92.5
1778	177.3	109.3	134.0	145.0	238.9	171.6	153.0	140.0	171.7	156.3	150.3	105.0	**154.4**
1779	114.7	165.7	118.0	145.0	140.0	113.7	143.0	112.0	111.0	124.0	114.0	110.0	125.9
1780	70 0	98.0	98.0	95.0	107.2	88.0	86.0	86.0	93.7	77.0	60.0	58.7	84.8
1781	98 7	74.7	53.0	68.3	104.7	97.7	73.5	66.0	51.0	27.3	67.0	35 2	68.1
1782	54 0	37.5	37.0	41.0	54.3	38.0	37.0	44.0	34.0	23.2	31.5	30 0	38 5
1783	28.0	38.7	26.7	28.3	23.0	25.2	32.2	20.0	18.0	8.0	15.0	10 5	22.8
1784	13.0	8.0	11.0	10.0	6.0	9.0	6.0	10.0	10.0	8.0	17.0	14.0	10.2
1785	6 5	8.0	9.0	15.7	20.7	26.3	36.3	20.0	32.0	47.2	40.2	27.3	24 1
1786	37 2	47.6	47.7	85.4	92.3	59.0	83.0	89.7	111.5	112.3	116.0	112 7	82.9
1787	134.7	106.0	87.4	127.2	134 8	99 2	128 0	137 2	157 3	157 0	141.5	174 0	**132.0**
1788	138.0	129.2	143.3	108.5	113.0	154.2	141.5	136.0	141.0	142.0	94.7	129.5	130.9
1789	114.0	125.3	120.0	123.3	123 5	120 0	117 0	103.0	112 0	89.7	134.0	135.5	118.1
1790	103.0	127.5	96.3	94.0	93.0	91.0	69.3	87.0	77.3	84.3	82.0	74 0	89.9
1791	72.7	62.0	74.0	77.2	73.7	64.2	71.0	43.0	66.5	61.7	67.0	66.0	66.6
1792	58.0	64.0	63.0	75.7	62.0	61.0	45.8	60.0	59.0	59.0	57.0	56 0	60.0
1793	56.0	55.0	55.5	53.0	52.3	51.0	50.0	29.3	24.0	47.0	44.0	45.7	46 9
1794	45.0	44.0	38.0	28.4	55.7	41.5	41.0	40.0	11.1	28.5	67.4	51.4	41.0
1795	21.4	39.9	12.6	18.6	31.0	17.1	12.9	25.7	13.5	19.5	25.0	18.0	21.3
1796	22.0	23.8	15.7	31.7	21.0	6.7	26.9	1.5	18.4	11.0	8.4	5.1	16.0
1797	14.4	4.2	4.0	4.0	7.3	11.1	4.3	6.0	5.7	6.9	5.8	3 0	6 4
1798	2.0	4.0	12 4	1.1	0.0	0 0	0.0	3.0	2 4	1 5	12 5	9 9	4 1
1799	1.6	12 6	21 7	8 4	8 2	10 6	2.1	0 0	0 0	4 6	2.7	8 6	6 8
1800	6.9	9 3	13.9	0 0	5 0	23 7	21.0	19.5	11 5	12 3	10 5	40 1	14 5
1801	27 0	29.0	30.0	31.0	32.0	31.2	35.0	38.7	33.5	32.6	39.8	48 2	34 0
1802	47.8	47.0	40.8	42.0	44.0	46.0	48.0	50.0	51.8	38.5	34.5	50 0	45 0
1803	50.0	50.8	29.5	25.0	44.3	36.0	48.3	34.1	45.3	54.3	51.0	48 0	43 1

TABLE 1—*Final relative sunspot-numbers, whole disc*—Continued

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1844	45.5	48.5	48.0	50.5	35.4	34.8	29.5	43.1	53.0	22.5	61.0	60.0	47.5
1845	64.0	44.1	51.4	37.5	39.0	40.5	37.6	42.7	44.4	25.4	41.0	38.5	42.2
1846	39.0	29.7	32.7	27.7	27.4	25.7	30.0	20.3	24.4	27.0	25.0	24.0	28.1
1847	22.0	12.2	9.0	25.8	19.0	12.0	12.1	13.0	5.7	8.0	2.6	0.0	10.4
1848	0.0	4.5	0.6	12.3	13.5	13.5	0.7	5.0	11.7	4.7	1.5	12.3	8.2
1849	7.2	0.2	0.7	2.5	2.0	7.7	0.3	0.2	0.4	0.0	0.0	0.0	2.5

TABLE 1—*Final relative sunspot-numbers, whole disc*—Continued

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1860	81.5	88.0	98.9	71.4	107.1	108.6	116 7	100 3	92.2	90.1	97 9	95 6	**95.7**
1861	62.3	77 8	101.0	98.5	56 8	87.8	78.0	82 5	79.9	67.2	53 7	80.5	77.2
1862	63.1	64.5	43.6	53.7	64.4	84.0	73.4	62 5	66.6	42 0	50 6	40.9	59.1
1863	48.3	56.7	66.4	40.6	53.8	40.8	32.7	48 1	-22.0	39.9	37.7	41.2	44.0
1864	57.7	47.1	66.3	35.8	40.6	57 8	54.7	54.8	28.5	33.9	57 6	28.6	47.0
1865	48.7	39.3	39.5	29.4	34.5	33.6	26.8	37.8	21 6	17.1	24 6	12.8	30.5
1866	31.6	38.4	24.6	17.6	12.9	16.5	9.3	12 7	7 3	14 1	9.0	1.5	16 3
1867	0.0	0.7	9 2	5.1	2.9	1.5	5.0	4.9	9.8	13.5	9.3	25.2	7.3
1868	15.6	15.8	26.5	36 6	26.7	31.1	28.6	34 4	43 8	61.7	59.1	67.6	37.3
1869	60.9	59.3	52.7	41.0	104.0	108.4	59.2	79.6	80.6	59 4	77 4	104 3	73.9
1870	77.3	114.9	159.4	160.0	176.0	135.6	132 4	153.8	136.0	146 4	147.5	130 6	**139.1**
1871	88.3	125.3	143.2	162.4	145.5	91.7	103 0	110 0	80.3	89.0	105 4	90.3	111 2
1872	79.5	120.1	88.4	102.1	107.6	109 9	105.5	92.9	114.6	103 5	112 0	83.9	101.7
1873	86.7	107.0	98 3	76.2	47.9	44.8	66 9	68.2	47.5	47.4	55 4	49.2	66 3
1874	60.8	64.2	46.4	32.0	44.6	38 2	67.8	61.3	28.0	34.3	28 9	29.3	44.7
1875	14.6	22.2	33.8	29.1	11.5	23.9	12.5	14.6	2 4	12.7	17.7	9.9	17.1
1876	14.3	15.0	31.2	2.3	5.1	1.6	15.2	8.8	9.9	14 3	9 9	8.2	11.3
1877	24.4	8.7	11.7	15.8	21.2	13 4	5 9	6 3	16 4	6.7	14.5	2.3	12 3
1878	3.3	6.0	7.8	0.1	5.8	6.4	0.1	0.0	5.3	1 1	4.1	0 5	3.4
1879	0.8	0.6	0.0	6.2	2.4	4.8	7.5	10.7	6.1	12.3	12.9	7.2	6.0
1880	24.0	27.5	19.5	19.3	23.5	34.1	21 9	48.1	66.0	43.0	30 7	29 6	32.3
1881	36.4	53.2	51.5	51.7	43.5	60.5	76.9	58 0	53.2	64.0	54.8	47.3	54.3
1882	45.0	69.3	67.5	95.8	64.1	45.2	45.4	40.4	57.7	59 2	84.4	41.8	59.7
1883	60.6	46.9	42.8	82.1	32.1	76 5	80 6	46 0	52.6	83.8	84.5	75.9	**63.7**
1884	91.5	86.9	86 8	76.1	66.5	51.2	53 1	55.8	61.9	47.8	36 6	47.2	63.5
1885	42.8	71.8	49 8	55.0	73 0	83 7	66 5	50.0	39.6	38 7	33.3	21.7	52.2
1886	29.9	25.9	57.3	43.7	30.7	27.1	30.3	16.9	21.4	8 6	0 3	12.4	25.4
1887	10.3	13.2	4.2	6.9	20.0	15.7	23.3	21.4	7.4	6.6	6.9	20.7	13.1
1888	12.7	7.1	7.8	5.1	7.0	7 1	3.1	2 8	8.8	2.1	10.7	6.7	6.8
1889	0.8	8.5	7.0	4 3	2.4	6 4	9 7	20 6	6 5	2.1	0.2	6.7	6.3
1890	5.3	0.6	5.1	1.6	4.8	1.3	11 6	8 5	17.2	11.2	9 6	7.8	7.1
1891	13.5	22.2	10 4	20.5	41.1	48 3	58.8	33 2	53.8	51.5	41.9	32 2	35.6
1892	69.1	75.6	49 9	69.6	79.6	76 3	76 8	101 4	62 8	70 5	65 4	78.6	73.0
1893	75.0	73.0	65.7	88.1	84.7	88 2	88 8	129.2	77 9	79.7	75 1	93 8	**84.9**
1894	83.2	84.6	52.3	81.6	101.2	98.9	106.0	70.3	65.9	75 5	56.6	60 0	78.0
1895	63.3	67.2	61.0	76.9	67.5	71.5	47.8	68.9	57.7	67 9	47.2	70.7	64 0
1896	29.0	57.4	52.0	43.8	27.7	49.0	45.0	27.2	61.3	28.4	38.0	42 6	41 8
1897	40.6	29.4	29.1	31 0	20.0	11.3	27.6	21.8	48 1	14.3	8.4	33.3	26 2
1898	30.2	36 4	38.3	14.5	25.8	22 3	9 0	31 4	34.8	34 4	30.9	12.6	26 7
1899	19.5	9 2	18 1	14 2	7.7	20 5	13 5	2 9	8 4	13 0	7 8	10.5	12.1
1900	9.4	13.6	8 6	16.0	15 2	12 1	8 3	4.3	8 3	12 9	4 5	0.3	9.5
1901	0.2	2.4	4.5	0.0	10.2	5 8	0.7	1.0	0 6	3 7	3 8	0.0	2.7
1902	5 2	0 0	12.4	0 0	2.8	1 4	0 9	2 3	7 6	16 3	10 3	1.1	5.0
1903	8.3	17 0	13.5	26 1	14 6	16 3	27 9	28 8	11 1	38 9	44 5	45 6	24.4
1904	31.6	24.5	37.2	43 0	39.5	41 9	50 6	58 2	30 1	54 2	38 0	54 6	42.0
1905	54.8	85.8	56.5	39 3	48.0	49 0	73 0	58 8	55 0	78 7	107 2	55 5	**63 5**
1906	45.5	31 3	64 5	55.3	57 7	63 2	103 6	47 7	56 1	17 8	38 9	64 7	53 8
1907	76 4	108 2	60 7	52 6	42 9	40 4	49 7	54 3	85 0	65 4	61 5	47 3	62 0
1908	39 2	33 9	28 7	57 6	40 8	48 1	39 5	90 5	86 9	32 3	45 5	39 5	48 5
1909	56 7	46 6	66 3	32 3	36 0	22 6	35 8	23 1	38 8	58 4	55 8	54 2	43 9
1910	26.4	31 5	21 4	8 4	22 2	12 3	14 1	11 5	26 2	38 3	4 9	5 8	18 6
1911	3 4	9 0	7 8	16.5	9 0	2 2	3 5	4 0	4 0	2 6	4 2	2 2	5 7
1912	0 3	0 0	4 9	4 5	4.4	4 1	3 0	0 3	9 5	4 6	1 1	6 4	3 6
1913	2 3	2 9	0 5	0 9	0 0	0 0	1 7	0 2	1 2	3 1	0 7	3 8	1 4
1914	2.8	2 6	3 1	17 3	5 2	11 4	5 4	7 7	12 7	8 2	16 4	22 3	9 6
1915	23 0	42 3	38 8	41 3	33 0	68 8	71 6	69 6	49 5	53 5	42 5	34 5	47 4
1916	45 3	55 4	67 0	71 8	74 5	67 7	53 5	35 2	15 1	50 7	65 6	53 0	57 1

TABLE 1—*Final relative sunspot-numbers, whole disc*—Continued

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1917	74.7	71.9	94.8	74.7	114.1	114.9	119.8	154.5	129.4	72.2	96.4	129.3	**103.9**
1918	96.0	65.3	72.2	80.5	76.7	59.4	107.6	101.7	79.9	85.0	83.4	59.2	80.6
1919	48.1	79.5	66.5	51.8	88.1	111.2	64.7	69.0	54.7	52.8	42.0	34.9	63.6
1920	51.1	53.9	70.2	14.8	33.3	38.7	27.5	19.2	36.3	49.6	27.2	29.9	37.6
1921	31.5	28.3	26.7	32.4	22.2	33.7	41.9	22.8	17.8	18.2	17.8	20.3	26.1
1922	11.8	26.4	54.7	11.0	8.0	5.8	10.9	6.5	4.7	6.2	7.4	17.5	14.2
1923	4.5	1.5	3.3	6.1	3.2	9.1	3.5	0.5	13.2	11.6	10.0	2.8	5.8
1924	0.5	5.1	1.8	11.3	20.8	24.0	28.1	19.3	25.1	25.6	22.5	16.5	16.7
1925	5.5	23.2	18.0	31.7	42.8	47.5	38.5	37.9	60.2	69.2	58.6	98.6	44.3
1926	71.8	70.0	62.5	38.5	64.3	73.5	52.3	61.6	60.8	71.5	60.5	79.4	63.9
1927	81.6	93.0	69.6	93.5	79.1	59.1	54.9	53.8	68.4	63.1	67.2	45.2	69.0
1928	83.5	73.5	85.4	80.6	76.9	91.4	98.0	83.8	89.7	61.4	50.3	59.0	**77.8**
1929	68.9	64.1	50.2	52.8	58.2	71.9	70.2	65.8	34.4	54.0	81.1	108.0	65.0
1930	65.3	49.2	35.0	38.2	36.8	28.8	21.9	24.9	32.1	34.4	35.6	25.8	35.7
1931	14.6	43.1	30.0	31.2	24.6	15.3	17.4	13.0	19.0	10.0	18.7	17.8	21.2
1932	12.1	10.6	11.2	11.2	17.9	22.2	9.6	6.8	4.0	8.9	8.2	11.0	11.1
1933	12.3	22.2	10.1	2.9	3.2	5.2	2.8	0.2	5.1	3.0	0.6	0.3	5.7

TABLE 2—*Final relative sunspot-numbers, central zone only, 1917-1933*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1917	28.6	32.6	34.4	28.4	49.3	45.1	54.8	54.8	50.2	25.0	38.8	50.4	**41.0**
1918	41.0	26.8	31.7	29.2	30.3	29.2	49.7	40.6	32.8	34.6	33.4	23.5	33.6
1919	21.9	29.5	29.1	21.2	43.0	50.3	26.7	29.3	21.2	21.7	17.8	16.5	27.4
1920	27.2	25.6	35.1	5.6	15.1	16.0	10.9	5.7	15.2	23.5	11.9	13.0	17.1
1921	15.1	13.3	11.9	12.3	9.4	17.7	21.9	11.2	6.6	8.3	5.4	8.9	11.8
1922	5.5	13.8	27.2	5.2	5.1	1.6	5.7	2.5	2.3	2.2	2.8	9.7	7.0
1923	0.7	1.2	1.4	3.1	1.4	6.0	0.9	0.2	3.1	4.2	1.1	0.6	2.0
1924	0.1	0.5	0.5	4.4	5.8	2.6	11.5	7.0	9.5	7.1	8.1	6.7	5.3
1925	0.6	9.2	4.8	7.4	15.0	12.8	14.7	14.1	22.2	22.9	18.2	33.2	14.6
1926	24.6	22.9	22.1	9.3	24.5	32.8	26.6	18.9	24.6	27.8	27.9	29.1	24.3
1927	27.4	39.1	25.0	39.5	35.4	25.3	21.0	18.2	26.2	24.0	29.8	18.7	27.5
1928	40.9	32.6	36.8	39.6	35.7	49.7	44.8	42.2	44.3	31.7	22.8	30.0	**37.6**
1929	33.6	27.3	20.9	21.2	27.3	29.7	33.2	28.7	14.5	25.2	35.6	48.4	28.8
1930	28.1	21.5	16.8	17.3	18.1	14.8	11.6	12.0	13.8	19.3	15.3	10.4	16.6
1931	5.1	17.4	14.7	12.3	9.9	6.7	8.6	6.2	8.3	3.9	10.6	7.3	9.3
1932	4.4	5.8	4.5	5.2	7.1	9.3	3.9	3.6	1.8	3.5	3.5	3.4	4.7
1933	4.4	9.5	3.7	1.7	1.1	2.5	0.7	0.0	2.4	1.8	0.3	0.3	2.4

TABLE 3—*Intensity of ultra-violet radiation (Mount Wilson) 1924-1933*
[Figures give ratio ultra-violet ($\lambda = 0.32\,\mu$) to green ($\lambda = 0.50\mu$)—ratio June 1924 = 1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct .	Nov.	Dec.	Mean
1924	...	...	...	...	0.99	0.99	1.07	1.11	1.20	...	...	...	1.07
1925	..			1.29	1.37	1.35	1.24	1.33	1.38	1.50	1.57	1.37	1.38
1926	1.43	1.39	1.35	1.28	1.31	1.29	1.33	1.31	1.33	1.49	1.38	1.49	1.37
1927	1.46	1.51	1.47	1.51	1.44	1.38	1.24	1.24	1.28	1.28	1.22	1.20	1.35
1928	1.18	1.28	1.30	1.30	1.19	1.22	1.26	1.13	1.12	1.21	1.30	1.32	1.23
1929	1.25	1.37	1.36	1.29	1.22	1.19	1.26	1.25	1.24	1.27	1.19	1.20	1.27
1930	1.52	1.39	1.34	1.15	1.19	1.18	1.10	1.14	1.22	1.13	1.16	1.13	1.22
1931	1.18	1.15	1.10	1.08	1.00	0.95	0.94	0.97	1.05	1.00	1.23	1.16	1.07
1932	1.23	1.05	0.93	0.88	0.91	0.89	0.91	0.94	0.92	0.90	0.91	1.02	0.96
1933	0.89	1.14	1.09	1.06	1.08	1.02	0.96	1.05	1.07	0.97	1.04	1.02	1.03

Editor's note—In view of the numerous requests received for the final values of measures of solar activity and the depletion of the supply of reprints of the table of observed relative sunspot-numbers for 1749 to 1924 published in this JOURNAL (**30**, 83-86, 1925), the table of final observed relative sunspot-numbers is reprinted above with additions through the year 1933. For detailed accounts of the derivation of these numbers the interested reader may be referred to the various issues of the *Astronomische Mitteilungen*, begun by Wolf and continued by Wolfer and Brunner. It has seemed desirable also to extract in Tables 2 and 3 the values of relative sunspot-numbers applying for the central zone only and the values of intensity of ultra-violet radiation so far as these have been observed. Tables 2 and 3 are extracted from the "Bulletin for character-figures of solar phenomena" of the International Astronomical Union published by the Swiss Federal Observatory in Zürich.

The cooperating observatories now supplying data upon which are based the tabulations of solar phenomena given in the above-mentioned *Bulletin* and in the above tables are: Arcetri-Firenze, Cambridge (England), Catania, Coimbra, del Ebro, Ewhurst (Mt. Evershed), Greenwich and Cape Town, Kodaikanal, Kiew, Kyoto-Kwasan, Lyons, Meudon-Paris, Mount Wilson, Roma-Campidoglia, South Hadley, Stonyhurst, Tokyo, Wellington, and Zürich.

The following remarks quoted from the introduction by W. Brunner to the first number of the "Bulletin for character-figures of solar phenomena" published in Zürich, November 1928, give details regarding the preparation of these character-figures:

"For the research of the relationship between solar phenomena and certain terrestrial phenomena it is important to have simple character-figures which denote the daily intensity of the various phenomena of the Sun's surface. . . . .

"The already established relationships appear to depend upon corpuscular emissions projected from the Sun in limited streams. Hence the figures should refer only to a certain smaller central part of the Sun's surface which is turned directly towards the Earth. As such a central part a Sub-Committee of the International Astronomical Union has chosen the Sun's surface between meridians situated 30° on either side of the central meridian.

"The choice of this central part is of course rather arbitrary. The chief thing is to take a smaller part of the surface which is turned more directly to the Earth than the limb parts. The Committee has decided on the meridian zone, and not as was first proposed on a central-circle zone of a diameter equal to half the Sun's diameter, considering that more seldom spots, but more frequently (especially in the limit positions of the Sun's equator) flocculi, can be present at higher latitudes than 30°, but still in position to affect the Earth.

"The *Bulletin* brings character-figures referring to the chosen meridian zone for spot-activity, ... further numbers to characterize the intensity of spot-activity on the whole visible disc, and character-figures for the intensity of ultra-violet radiation. . . . . . .

"The intensity of spot-activity for the whole disc, as well as for the central zone is expressed by the Wolf relative spot-number $r = k (10g + f)$ where g indicates the number of the observed groups (centers of activity) and f the total number of single spots and spot-nuclei. K is

the reduction-factor on Wolf's unit. It varies with the instrument, the observer, and the mode of observation. We also give the full weight 10 to such groups as have only partly entered the central zone, but we only count the spots that are already inside the central zone.

"In determining the daily relative number taken from our own and other observations it is not admissible to take simply the mean of all values, the conditions at the various stations at which the spots are counted being too different, for instance in Greenwich from photographic plates, in Catania and Lyons from projected images of different sizes, and in Zürich from visual observation. Further, it is very important that the homogeneity of the old Zürich spot-series should be maintained. Therefore, I take my own Zürich series as normal series. I have determined my reduction-factor on Wolf's unit by comparison of my observations with those of Professor Wolfer for the last three years. The factor is exactly the same as Professor Wolfer's, that is, 0.60. It is smaller than Wolf's unit-factor, because we count more small and smaller nuclei than Wolf did, and we pay more attention to the fact that large umbra-spots are mostly themselves broken up into various nuclei. In order to determine the reduction-factor for the series received from other observatories I determine the relative number $r = (10g + f)$ for each day, and fix the reduction-factor by comparing these numbers with my own of the same days. With this factor I reduce the relative numbers of other series on our Zürich series, and Zürich blank days are now filled up by the mean of the reduced relative numbers of other series."

EIDGENÖSSISCHE STERNWARTE,
    Zürich, Switzerland

THE MAGNETIC CHARACTER OF THE YEAR 1933 AND THE NUMERICAL MAGNETIC CHARACTER OF DAYS 1933

By G. van Dijk

The annual review of the "Caractère magnétique de chaque jour" for 1933 has been drawn up in the same manner as for preceding years.[1] Forty-nine observatories contributed to the quarterly tables, forty-eight of them sent complete data.

Table II (reproduced as Table 1 below) of the annual review, contains the mean character of each day for each month. The lists of calm days and disturbed days, and the days recommended for reproduction are also reprinted here as Table 2.

In the introduction a note has been inserted concerning the publication "Caractère magnétique numérique des jours." Volumes VI to IX have been published along with the tables of "Caractère magnétique de chaque jour"; they contain data of 1933 and belated data of 1932. Thirty-one observatories have sent lists for 1933, twenty-nine of them were complete.

1 — Mean magnetic character-numbers for each day of 1933 from data supplied by 48 magnetic observatories

ites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
13															
	1.2	0.8	0.2	0.0	0.0	1.2	0.8	0.3	0.1	0.0	0.1	0.1	0.1	0.7	1.2
	0.1	0.8	0.3	0.3	0.3	0.1	0.5	0.4	0.3	0.2	0.0	0.3	0.0	0.8	0.9
	0.4	0.4	0.5	0.2	0.0	0.1	0.1	0.2	0.0	0.4	0.8	0.4	0.8	0.6	0.2
	0.5	0.4	0.9	0.8	0.5	0.6	1.0	0.8	0.7	0.7	0.1	0.0	0.1	0.5	1.2
	1.9	1.1	0.8	1.0	0.8	1.0	0.7	0.1	0.0	0.1	0.1	0.1	0.4	1.0	0.9
	1.1	0.5	0.4	0.1	0.0	0.0	0.1	1.0	0.8	0.3	0.1	0.4	1.6	1.2	0.8
	0.5	0.4	0.5	0.4	0.3	0.4	0.2	0.9	1.3	0.9	0.9	0.4	0.1	0.1	0.0
	0.0	0.1	0.1	0.1	1.8	1.3	0.4	0.3	0.1	0.1	0.0	0.2	1.5	1.0	0.8
er	0.6	0.8	0.1	0.4	0.0	0.2	0.4	0.4	0.8	1.9	1.2	0.7	0.8	1.4	1.5
	0.1	0.3	0.2	0.7	1.3	0.9	1.6	1.0	1.2	1.1	0.9	1.1	1.3	1.3	0.6
er	0.4	0.6	0.9	1.1	0.7	1.6	1.5	1.5	1.0	0.8	1.1	0.4	0.2	0.1	0.1
r	0.1	0.4	1.2	1.3	1.4	0.8	1.0	0.2	1.5	1.3	0.6	0.2	0.3	0.1	0.1

ites	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Means
133																	
	0.5	0.2	0.1	1.2	0.9	0.1	1.4	1.1	1.1	0.9	1.0	1.4	1.2	0.9	0.7	0.5	0.65
	0.1	0.0	0.3	1.7	1.4	1.7	1.6	1.5	1.5	1.1	1.2	0.6	0.3				0.65
	0.1	0.4	1.5	1.5	1.6	1.5	1.5	1.5	1.5	1.0	0.6	1.1	0.9	0.8	0.6	0.6	0.71
	1.3	1.4	1.1	1.2	1.2	1.2	1.2	1.1	0.6	0.5	0.8	0.4	0.3	0.1	1.3		0.76
	0.6	0.8	1.1	0.7	0.2	0.2	0.3	0.2	0.1	0.3	0.0	0.7	0.6	1.1	1.2	1.2	0.62
	0.1	0.2	0.1	0.8	1.2	0.6	0.3	0.1	0.1	1.0	0.6	0.9	1.0	0.8	0.4		0.55
	0.3	1.0	1.0	0.3	0.5	0.1	0.3	1.5	1.6	0.5	0.7	1.1	0.2	0.2	0.1	0.3	0.54
	0.4	1.0	1.3	1.0	1.1	1.3	0.2	1.0	1.1	0.9	0.9	0.3	0.1	0.1	0.2	0.1	0.60
er	1.0	0.9	0.9	0.9	0.6	0.6	0.5	0.3	0.4	0.9	0.6	0.8	0.9	0.7	0.4		0.77
	0.1	0.6	1.2	0.2	0.4	0.1	0.2	0.4	0.8	0.9	0.9	0.3	0.1	0.0	0.2	0.2	0.65
er	0.2	0.0	0.5	0.6	0.6	1.0	0.4	0.5	0.1	0.3	0.0	1.1	0.6	0.4	0.2		0.63
r	0.2	0.4	0.9	0.6	0.3	0.4	0.3	0.2	0.0	0.3	0.4	0.4	0.8	0.5	0.0	0.2	0.53

[1]Terr. Mag., **33**, 203 (1928); **34**, 207 (1929); **35**, 178 (1930); **36**, 255 (1931); **37**, 259 (1932); **38**, 301-302 (1933).

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TABLE 2—*Dates of five magnetically calm and five most disturbed days with mean character-numbers during 1933*

Month	Calm days					Most disturbed days				
1933										
January	(0.05)	4,	5,	10,	11,	21	**1** (1.2),	**19** (1.2),	**22** (1.4),	**27** (1.4),	**28** (1.2)
February	(0.04)	6,	11,	13,	16,	17	**19** (1.7),	**21** (1.7),	**22** (1.6),	**23** (1.5),	**24** (1.5)
March	(0.08)	5,	6,	7,	9,	16	**18** (1.5),	**19** (1.5),	**20** (1.6),	**23** (1.5),	**24** (1.5)
April	(0.11)	11,	12,	13,	28,	29	**15** (1.2),	**16** (1.3),	**17** (1.4),	**19** (1.2),	**30** (1.3)
May	(0.06)	9,	10,	12,	24,	26	**1** (1.9),	**18** (1.1),	**29** (1.1),	**30** (1 2),	**31** (1.2)
June	(0.05)	5,	6,	16,	18,	24	**1** (1.1),	**13** (1.6),	**14** (1.2),	**20** (1.2),	**28** (1.0)
July	(0.08)	13,	14,	15,	21,	30	**9** (1.3),	**17** (1.0),	**23** (1.5),	**24** (1.6),	**27** (1.1)
August	(0.05)	1,	9,	10,	11,	31	**5** (1.8),	**6** (1.3),	**13** (1.5),	**18** (1.3),	**21** (1.3)
September	(0.23)	3,	5,	6,	23,	24	**9** (1.9),	**10** (1.2),	**13** (1.7),	**14** (1.4),	**15** (1.5)
October	(0.08)	1,	16,	21,	28,	29	**5** (1.3),	**7** (1.6),	**9** (1.2),	**13** (1.3),	**14** (1.3)
November	(0.08)	14,	15,	17,	24,	26	**6** (1.6),	**7** (1.5),	**8** (1.5),	**11** (1.1),	**27** (1.1)
December	(0.06)	1,	14,	15,	24,	30	**3** (1.2),	**4** (1.3),	**5** (1.4),	**9** (1.5),	**10** (1.3)

DAYS RECOMMENDED FOR REPRODUCTION
**May 1, 1933; *April 30, August 5, September 9, 1933.

KONINKLIJK NEDERLANDSCH METEOROLOGISCH INSTITUUT,
        De Bilt, Utrecht, Holland

JOHANNES PAULUS VAN DER STOK

By E. van Everdingen

Johannes Paulus van der Stok was born January 14, 1851, at Zuilen, studied from 1867 at the University of Utrecht, and took his degree of doctor in mathematics and physics in 1874. Buys Ballot was one of his teachers.

After having been about two years teacher at the gymnasium of The Hague, Dr. Van der Stok was appointed sub-director of the Royal Magnetical and Meteorological Observatory at Batavia. In 1882 he succeeded Dr. Bergsma as director of the Observatory and resigned as such in 1899, when he returned to Holland.

In September 1899 Dr. Van der Stok was appointed director of the "Section Observations at Sea" (afterwards called "Section of Oceanography and Maritime Meteorology") at the Meteorological Institute of De Bilt; he retired from this post October 31, 1923. He died at Utrecht, after some years of illness, March 29, 1934, at the age of eighty-three years. [The photograph, of which Plate 3 is a reproduction, was taken October 31, 1923; the signature is one of November 22, 1932.]

Under the direction of Van der Stok the Batavia Observatory extended its task in many directions and played an important part in the domain of international cooperation, for instance, in terrestrial magnetism, seismology, and cloud-observations. When he left, the Observatory was well known in these fields all over the globe.

His first publications dealt among others with periodicities in terrestrial magnetism and meteorology. Among those relating to magnetic observations may be mentioned: Sur la variation de la déclinaison magnétique en Néerlande, déduite de vingt années d'observations au Helder (1878); L'influence de la lune sur les mouvements de l'aiguille aimantée (1881); Sur le calcul des observations horaires de la force horizontale du magnétisme terrestre (1884). These publications appeared in *Archives néerlandaises des sciences exactes et naturelles*. Other papers were: Bijdrage tot de kennis van den invloed der zon op de dagelijksche beweging der magneetnaald [Contribution to the knowledge of the influence of the Sun upon the daily oscillation of the magnetic needle] (1882); On the influence of the moon upon the diurnal variation of the magnetic declination at Batavia (1886); De Hornstein'sche 26-daagsche periode, afgeleid uit meteorologische en magnetische waarnemingen te Batavia, Petersburg en Praag [The Hornstein 26-day period, as deduced from meteorological and magnetical observations at Batavia, Petersburg, and Prague].

However, as his most important work must be considered his ingenious studies on tidal movements. He succeeded in completely disentangling the very complicated tidal phenomena in the East Indian Archipelago and thanks to his work the tidal movements in the Dutch East Indies are better known than in any other like region of the Earth. The results have been published in a large number of papers. Among these are: Harmonische analyse der getijden in de Java Zee [Harmonic analysis of tides in the Java Sea] (1899) and Studien over getijden in den

Indischen Archipel [Studies in tides in the Indian Archipelago] (1890-1896). His standard work is Wind and weather, currents, tides and tidal streams in the East Indian Archipelago, with atlas (Batavia, 1897).

After his return to Holland at the Meteorological Institute of De Bilt, Dr. Van der Stok continued his keen interest in all branches of science, including magnetic observations. He was a representative of the Netherlands in the assemblies of the International Association of Seismology and was vice-president of the meetings at Rome (1906) and The Hague (1907).

Besides the oceanographic atlases and tables of the Indian and Atlantic oceans, published under his supervision, a large number of his papers appeared among the papers of the Royal Netherlands Meteorological Institute. Among these are: Etude des phénomènes de marée sur les côtes néerlandaises (1904-1910); Ueber Oberflächentemperaturen des Meereswassers unweit des niederländischen Küste (1906); Elementaire Theorie der Getijden: Getijconstanten in den Indischen Archipel [Théorie élémentaire des marées: Constantes des marées dans l'archipel indien] (1910), German translation by Prof. Herrmann published in Annalen der Hydrographie und Maritimen Meteorologie (1911); Das Klima des Südöstlichen Teiles der Nordsee unweit der niederländischen Küste (1912), deduced from observations of lightships.

Other papers, dealing with oceanography, meteorology, climatology, geography, studies of frequencies, correlations, harmonic analysis, etc., were published in the Proceedings of the Royal Academy of Sciences of Amsterdam, the Tijdschrift van het Koninklijk Nederlandsch Aardrijkskundig Genootschap [Journal of the Royal Netherlands Geographical Society], and elsewhere.

Dr. Van der Stok was a member of a large number of scientific societies in the Netherlands and abroad, a member of the Royal Academy of Sciences of Amsterdam, and an honorary member of the Royal Meteorological Society (London). He was honored by designation as knight of the order of de Nederlandsche Leeuw [the Netherlands Lion] and as Commander of the order of the Crown of Italy.

In 1921, when Dr. Van der Stok reached the age of seventy years, the Dutch Navigation Companies presented him with his painted portrait as an appreciation of his important contributions to navigation. According to his wishes, his family has presented this portrait to the Meteorological Institute at De Bilt. There it will find a place in his former study and will constitute a lasting remembrance of a highly intelligent man and a warmhearted friend. Dr. Van der Stok will be gratefully remembered by all who had the opportunity of making his acquaintance or of getting acquainted with the results of his investigations.

LETTERS TO EDITOR

PROVISIONAL SUNSPOT-NUMBERS FOR JUNE TO AUGUST, 1934

(Dependent alone on observation at Zürich Observatory and its station at Arosa)

Day	June	July	Aug.	Day	June	July	Aug.
1	0	0	0	17	30	17	17
2	0	0	0	18	26	17	22
3	0	0	0	19	25	17	13
4	0	0	. .	20	14^b	8	0
5	0	0	0	21	16	7	0
6	0	8^d	8^d	22	10	0	0
7	0	8	8	23	10	0	7
8	0	11	9	24	8	7	8
9	7	11	10	25	8	8	0
10	0	18	11	26	8	0	0
11	0	24^d	12	27	0	7?	. .
12	0	24^b	E21^{ac}	28	0	7	0
13	0	25	21	29	0	0	0?
14	0^d	24	23	30	0	0	7
15	11	17?	24	31		0	0?
16	27	23	26				
				Means..	6.7	9.3	8.5
				No. days	30	31	29

Mean for quarter April to June, 1934, 12.5 (88 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a larger group through the central meridian.
[c]New formation of a large or average-sized center of activity: E, on the eastern part of the Sun's disc; W, on the western part; M, in the central zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

Zürich, Switzerland   W. BRUNNER

NOTE REGARDING AURORAE AND EARTH-CURRENTS

In the final paragraph of my paper "Auroræ and Earth-Currents" in the June issue of the JOURNAL (**39**, 103-109, 1934) appears the statement that the results of the British Antarctic Expeditions led Dr. Chree to the conclusion that there is no definite relationship between auroral and magnetic activities. My attention has been called by Dr. C. S. Wright to the fact that this statement is inaccurate unless a very specialized and unusual significance is given to the word *definite*, since the records of those expeditions do show a certain degree of correlation which is high in some respects. The inadequacy of the reference may best be corrected by quoting from Dr. Wright's report "Observations on the Aurora, British (Terra Nova) Antarctic Expedition, 1910-1913" (Harrison and Sons, Ltd., London, 1921), which was critically reviewed by Dr. Chree prior to publication. On page 34 the report states:

"The whole relation between magnetic and auroral disturbances . . . may be stated as follows:

"(1) A fairly strong correspondence between *periods* of disturbed auroral and magnetic conditions, particularly in the stronger disturbances.

"(2) A *slight* correspondence between disturbed conditions of both types *in the same hour*.

"(3) A possible secondary maximum in the mean character-number for disturbance, of both types, occurring about the same time in the afternoon, in both cases. (The secondary maximum in the mean magnetic character-number seems to be connected with magnetic disturbances of the 'special type', while the secondary auroral maximum seems to be connected with the occurrence of brilliant, colored, and quickly moving auroræ.)"

The force of these conclusions depends on the emphasis placed on the second basis of comparison and, since this was the basis for the correlations worked out for the College-Fairbanks earth-current data, it was unduly stressed in my reference.

W. J. Rooney

Department of Terrestrial Magnetism,
    Carnegie Institution of Washington,
        Washington, D. C.

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, APRIL, MAY, AND JUNE, 1934

A magnetic storm began May 11 at 20^h 8^m, G.M.T., and ended May 12 at about 8^h; the range in the horizontal intensity (H) was 75γ. The only sunspot-group observed on May 11 was very near the west limb of the Sun. Although the small group which crossed the central meridian on May 10.6, 9° north of the center of the disc, was not seen on May 11, its position was marked by bright hydrogen flocculi. Small bright hydrogen flocculi had been observed in this group on May 9 also; clouds prevented observations on May 10.

A magnetic storm in which the range in H was 116γ began May 18 at about 3^h, G.M.T., and ended May 19 at about 2^h. A sudden increase in H was recorded on May 18 at 4^h 06^m, G.M.T. Bright hydrogen flocculi were observed on several days in the group of spots which, on May 18, was 19° east. This group crossed the central meridian on May 19.6, 29° south of the center of the solar disc. Bright hydrogen flocculi were also observed in another group which was 27° north and 65° east on May 18.

From October 1, 1933 to July 1, 1934, thirteen groups of the old cycle and twenty-one of the new cycle were observed. Since all except one of the twenty-one groups of the new cycle had magnetic polarities opposite to those of the waning cycle, the reversal of polarities at the present minimum may be considered as well established. The new cycle is developing so rapidly that the time of minimum activity has certainly been passed, probably in November or December, 1933. The length of the last cycle was, therefore, approximately 10.3 years.

Day	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.	K_2		$H\alpha B$		$H\alpha D$		No. groups	Mag'c char.
	A	B	A	B	A	B			A	B	A	B	A	B			A	B	A	B	A	B		
1	0.5	0	0.5	0	0.5	0	1	0.5	....	....	....	....	....	....	....	0	1	1	1	1	1	1	0	0
2	....	....	....	....	....	....	1	0	0	0	0	0	0	0	0	0.5	1	1	1	2	1	1	0	0
3	0.5	0.5	0.5	0	0.5	0	1	0	0	0	0	0	0.5	0	0	0.5	0.5	0.5	1	1	1	0	0	0
4	0.5	0.5	0.5	0	1	0	1	0.5	0.5	0.5	0.5	0.5	0.5	0	1	0.5	....	....	....	....	....	....	....	0.5
5	0.5	0.5	0.5	0	1	0	1	0.5	0.5	0.5	1[e]	1.5[e]	0.5	0	1[c]	0	....	....	....	....	....	....	....	0.5
6	1	0.5	0.5	0.5	0.5	0	0	0.5	0.5	1	1	1	0.5	0.5	1	0	....	....	....	....	....	....	....	0.5
7	0.5	0.5	0.5	0.5	1	0.5	0	0	0.5	0.5	1	0.5	1	1	2	0	0	0	0	0	0.5	0	0	0
8	0.5	0.5	0.5	0.5	1	0.5	0	0	0.5	0	1	0.5	0.5	1	2	0	0	0	0	0	0	0	0	0.5
9	0.5	1	0.5	0.5	1	0.5	0	0	0.5	0.5	1	0.5	0.5	0	2	0	0	0	0.5	0	0.5	0	0	0
10	0.5	0.5	0.5	0.5	0.5	0.5	0	0	....	....	....	....	....	....	....	0	0	0	0.5	0	0.5	0	0	0
11	0.5	0	0.5	0	1	0.5	0	0	0.5	0.5	0.5	0.5	0.5	0	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0	0
12	0.5	0	0.5	0	1	0.5	0	0	0.5	0	0.5	0	0.5	0	0	0.5	0.5	0	0.5	0	0.5	1	0	0.5
13	0	0	0	0	0.5	0	0	0	1	0	1	0	0.5	0	2	0	1	0	1	0	0.5	0	0	0
14	0	0	0	0	0	0	2	0	1	0.5	1.5	0.5	0.5	1	2	0	1	0	1	0	1	0	1	0
15	....	....	....	....	....	....	2	0	1.5	0.5	2	0.5	0.5	0.5	2	0	1.5	0.5	1.5	0.5	1	0	1	0.5
16	1	0	1	0	0.5	0	2	0.5	2	0.5	2	0.5	0.5	0.5	2	0	1.5	0	2	0	0.5	0.5	2	0
17	1	0	1	0	0.5	0	2	0	2.5	0.5	2.5[f]	0.5	0.5	0	4	0	1.5	0	2	0	0.5	0	2	....
18	1	0	2	0	0.5	0	2	0	2.5	1	2.5[f]	1	0.5	0	3	1	1.5	0.5	2	0.5	1	0	2	0.5
19	1	0	1.5	0	0.5	0	1	0	2.5	2	2.5[f]	2[f]	0.5	0	3[d]	1	2	2	2.5[g]	2.5[g]	2	1	1	0
20	1.5	1.5	1.5	1.5	0.5	0.5	1	0	2.5	1	2.5[f]	0.5[f]	0.5	0	3	0	2	2	2?	2?	1.5?	0.5?	1[b]	0
21	1.5	1.5	1.5	1.5	0.5	0.5	1[a]	0	2.5	0.5	2.5[f]	0	1	0	4	0	2	2.5	2?	2?	1.5?	0.5?	1	0
22	1.5	1.5	1.5	1.5	0.5	0.5	1	0	2.5	1	2.5[f]	1.5[f]	0.5	0	4[d]	0	1.5	2	2	2	1	0	1	0
23	1	0.5	1	0.5	0.5	0	1	0	2	1	2.5	1	0.5	0	4	0.5	1	0.5	2	0.5	0.5	0	1	0
24	1	0	1	0	0	0	1	0.5	2	0.5	2	0.5	0.5	0	3	0	1	0	1	0	1	0	1	0
25	1	0	1	0	0.5	0	1	0	....	....	....	....	....	....	....	0.5	0.5	0.5	0.5	0.5	0.5	0	1	0
26	1	0	1	0	0	0	1	0	....	....	....	....	....	....	....	0	0.5	0.5	0	0	0.5	0	1	0
27	1	0	1	0	0	0	2	0	....	....	....	....	....	....	1	0	0	0	0	0	1	0	0	0.5
28	0.5	0	0.5	0	0	0	2	0	1	0	1	0	1	0	2	0	0	0	0	0	1	0	0	0
29	0	0	0.5	0	0	0	1	0	1	0.5	1	0	0.5	0	0	0	0	0	0	0	1	0	0	0
30	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	....	....	....	....	....	....	0	0
31									1	1	1	1	1	0.5	0	0								
Mean	0.7	0.3	0.8	0.3	0.5	0.2	0.9	0.1	1.2	0.5	1.4	0.6	0.6	0.2	1.8	0.2	0.8	0.5	1.0	0.6	0.8	0.2	0.6	0.1

NOTE—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

?Indicates an uncertain value which should be given low weight.

[a] Passage of a large group through the central meridian within 25° of the center of the disc. [b] Passageof an average-sized group through the center of the disc. [c, d] Passage of an average-sized group through the central meridian within 20°, 30° of the center of the disc, respectively. [e] Very bright $H\alpha$ in south central group. [f] Very bright $H\alpha$ in large north and south groups. [g] Very bright $H\alpha$ in central group.

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AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1]

The data for terrestrial magnetism, sunspots, solar constant, and auroræ are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Electricity, (2) the type featuring the day other than normal by the letters *b, p, o,* and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots:

[1]For previous announcements see Terr. Mag., **35,** 184-185 and 252-253 (1930); **36,** 54, 141, 258-259, and 358-360 (1931); **37,** 85-89, 189-192, 408-411, and 484-487 (1932); **38,** 60-63, 148-151, 262-265, 335-339 (1933); **39,** 73-77, and 159-163 (1934).

Summary American URSI daily broadcasts

Date	Magnetism			Sun-spot		Solar constant		Aurora										May	Magnetism		
											Form										
	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.	Char.	Duration	Cloudiness	With-out rays	With rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Char.	Type	G. M. T. begin. distur.
			h m			*cal*			*hrs*							*h*			*h m*
1	1			1ᵃ	4ᵃ	.		3	½	0	HV	R	0 2	35	NW-N-E	9	0		
2	1			1ᵃ	4ᵃ	.		1	½	0	HV		0 2	20	NW-N-E	9	0		
3	0			1ᵃ	6ᵃ			1	4	2	HV		0 2	20	NW-N-E	10	1		
4	0			1	1	1.947	u	1	1	4	H.1	RB	0 2	30	NW-N-E	9	1		
5	1			1ᵃ	8ᵃ			1	4	2	HV	RB	0 6	45	W-N-E	9	0		
6	1			0	0			2	3	9	HV		0 2	70	W-N-SE	8	0		
7	0			0	0			9	0	10							0		
8	0			0	0			1	4	2	HV		0 2	15	NW-N-E	10	0		
9	0			0	0			9	0	10							0		
10	0			0	0	1.937	u	9	0	10							0		
11	0			0	0			1	1	2	HB	RB	0.2	25	NW-N-E	12	0		
12	0			0	0			1	2	1	HV		0.2	20	NW-N-E	10	1	20 06
13	0			0	0			1	1	6	HB		0.2	20	NW-N-NE	9	0		
14	0			2ᵃ	2ᵃ	1.927	f	1	1	6	HB		0.2	20	W-NE	9	0		
15	0			2ᵃ	6ᵃ			9	0	9							0		
16	1			2ᵃ	6ᵃ			1	1	4	HB		0 4	30	W-N-E	9	0		
17	0			2ᵃ	10ᵃ	1.945	f	0	0	8							0		
18	0			2ᵃ	13ᵃ	1.932	s	0	0	3							1		
19	0			1ᵃ	13ᵃ			9	0	10							1		
20	0			1ᵃ	15ᵃ			1	1	4	HB		0 2	7	N-NE	10	0		
21	0			1ᵃ	10ᵃ	1.961	u	9	0	10							0		
22	0			1ᵃ	8ᵃ	1.959	f	1	1	1	HB		0 2	40	NW-N-E	10	0		
23	0			1ᵃ	5ᵃ	1.963	f	9	0	10							0		
24	0			1ᵃ	2ᵃ	1.955	s	1	1	2	HB		0 2	35	NW-N-NE	11	0		
25	0			1ᵃ	2ᵃ	1.941	f	0	0	7							0		
26	0			1ᵃ	1ᵃ	1.943	f	0	0	6							0		
27	0			2ᵃ	3ᵃ	1.936	f	9	0	10							0		
28	0			2*	3*			9	0	10							0		
29	0			1ᵃ	1ᵃ			9	0	10							0		
30	0			0ᵃ	0ᵃ			9	0	10							0		
31																	0		
Mean	0.2			0.9	4.0	1.946		3 7	1.0	6							10	0.2	

Greenwich mean time for ending of storms: 7ʰ, May 13; 5ʰ, July 1; 5ʰ, July 4; 2ʰ, July 31.
**Auroral observations discontinued May 11 until fall.
ᵃA revision of value originally broadcast.

(1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N = k\,(10g + s)$, where k for Mount Wilson is about 0.7.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in footnotes to the Table.

The present values of the solar constant published in these tables are from Table Mountain, California, and have not so great weight as those formerly furnished from Montezuma. The colums headed solar constant show (1) the value in calories of the solar constant, and (2) by letters s, f, and u whether the determination was satisfactory, fair, or unsatisfactory, respectively.

of cosmic data, April to June, 1934

Sun-spot Groups	Sun-spot No.	Solar constant Value	Char.	Aurora** Char.	Aurora** Duration	Aurora** Cloudiness	Form Without rays	Form With rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Magnetism Char.	Magnetism Type	G. M. T. begin. distur. h	G. M. T. begin. distur. m	Sun-spot Group	Sun-spot No.	Solar constant Value	Char.	Date
		cal			hrs							h			h	m			cal		
...	...	......	...	0	0	3	...	...	...	...	....		0	...	..	..	0	0	1.950	f	1
0	0	......	...	0	0	4	...	...	...	...	....		0	...	..	..	0	0	1.944	f	2
0	0	......	...	0	0	8	...	...	...	...	....		0	...	..	..	0	0	1.944	f	3
1^a	3^a	......	...	0	0	7	...	...	...	...	....		0	...	..	..	...	...	1.957	f	4
1*	7*	......	...	0	0	2	...	...	...	...	....		1	...	..	..	...	...	......		5
1	10	1.949	f	0	0	8	...	...	...	...	....		1	...	..	..	...	...	1.966	f	6
2	5	1.964	f	0	0	6	...	...	...	...	....		0	...	..	..	0	0	1.963	s	7
2	11	1.962	f	9	0	10	...	...	...	...	....		0	...	..	..	0*	0*	1.945	f	8
2	13	1.955	n	9	0	10	...	...	...	...	....		1	...	..	..	0	0	1.958	s	9
...	...	......	...	..	...	...	...	...	...	...	....		0	...	..	..	0	0	1.955	f	10
1	2	1.921	u	..	...	...	...	...	...	...	....		0	...	..	..	0	0	1.956	s	11
0	0	1.953	f	..	...	...	...	...	...	...	....		1	...	..	..	0	0	1.951	s	12
2a*	4^a	1.953	u	..	...	...	...	...	...	...	....		0	...	..	..	0	0	1.957	f	13
2a*	5^a	......	...	..	...	...	...	...	...	...	....		0	...	..	..	1	1	......	...	14
2a*	$\|a$=	......	...	..	...	...	...	...	...	...	....		1	...	..	..	1^b	5^b	......	...	15
2a*	7a*	1.957	f	...	...	...	...	...	...	...	....		0	...	..	..	2^c	14^c	......	...	16
4a*	13a*	1.934	f	...	...	...	...	...	...	...	....		0	...	..	..	2^c	14^c	1.969	f	17
3a*	8^a	1.961	s	...	...	...	...	...	...	...	....		0	...	..	..	2	12	1.953	s	18
3a*	13^a	1.961	f	...	...	...	...	...	...	...	....		0	...	..	..	1^d	9^d	1.966	f	19
3	19	1.964	f	...	...	...	...	...	...	...	....		0	...	..	..	1^d	7^d	1.960	u	20
4*	17*	1.944	f	.	...	...	...	...	...	...	....		0	...	..	..	1^d	4^d	1.960	s	21
4	10	1.963	f	.	...	...	...	...	...	...	....		0	...	..	..	1	2	......	...	22
4	10	1.957	u	.	...	...	...	...	...	...	....		0	...	..	..	1^d	1^d	1.967	u	23
3	8	1.960	f	.	...	...	...	...	...	...	....		0	...	..	..	1	1	1.965	f	24
...	...	......	...	.	...	...	...	...	...	...	....		0	...	..	.	1^d	1^d	1.953	s	25
...	...	......	...	..	...	...	...	...	...	...	....		0	...	..	..	1^d	1^d	1.948	s	26
1	1	......	...	..	...	...	...	...	...	...	....		0	...	..	..	0	0	1.964	f	27
2	2	......	...	..	...	...	...	...	...	...	....		0	...	..	..	0	0	1.948	s	28
0	0	1.949	f	..	...	...	...	...	...	...	....		0	...	..	..	0	0	1.954	s	29
0	0	1.970	f	..	...	...	...	...	...	...	....		0	...	..	..	0	0	......	...	30
0	0	1.956	s	...	...	...	...	...	...	...	....			...								31
1.8	6.7	1.953	..	2.0	0	...	...	...	...	...	....	...	0.2	...	..	..	0.6	2.8	1.956	..	Mean

^{a}New cycle. ^{b}Old cycle, same group as reported preceding day. ^{c}Old cycle and one new cycle, ten and four spots respectively. ^{d}Old cycle. ^{e}Two new cycles, one old cycle. ^{f}One old cycle. ^{g}One old cycle, three new cycles. ^{h}Two new, two old cycles.

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Kennelly-Heaviside Layer heights, Washington, D. C., April to June 1934
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Fre-quency	Height	Date	Fre-quency	Height	Date	Fre-quency	Height
1934	*kc/sec*	*km*	*1934*	*kc/sec*	*km*	*1934*	*kc/sec*	*km*
Apr. 4	2530	120	May 2	2700	120	May 23	5900	400
" "	3000	140	" "	3200	140	" "	6200	480
" "	3270	200	" "	3300	*	" "	6300	*
" "	3400	170	" "	3370	230	" 30	2500	120
" "	3600	270	" "	3700	210	" "	3560	120
" "	3650	250	" "	4260	540	" "	3600	180
" "	4120	700	" "	4400	410	" "	3700	170
" "	4400	440	" "	4700	330	" "	3800	*
" "	4600	530	" "	5500	390, 460	" "	3840	220
" "	4800	910	" "	6000	410	" "	4380	570
" "	4900	*	" "	6300	570	" "	5000	560
" "	5200	530	" "	6400	*	June 6	2600	120
" "	5500	650	" 9	3100	120	" "	3400	100, 220
" "	5600	*	" "	3150	*	" "	3650	110, 160
" 11	2500	130	" "	3420	200	" "	4200	620
" "	3250	280	" "	3500	180	" "	4300	560
" "	3360	200	" "	4250	320	" "	4400	130, 600
" "	3400	270	" "	4400	*	" "	4500	*
" "	3850	200	" "	4500	360	" 13	2800	110
" "	4170	470	" "	4900	480	" "	4500	110
" "	4800	300	" "	5300	430	" "	4400	120
" "	5100	460	" "	5700	500	" "	5000	110
" "	5300	360	" "	6300	500	" "	5500	120
" "	5400	*	" "	6400	*	" "	6000	120
" "	5500	380	" 16	3000	130	" "	6400	100
" "	6200	510	" "	3100	*	" "	6600	*
" "	6300	*	" "	3600	*	" 20	2500	110
" 18	2800	130	" "	3720	200	" "	4000	120, 290
" "	3250	120	" "	3840	190	" "	4150	120, 270
" "	2700	140	" "	3970	340	" "	4400	120, 480
" "	3350	200	" "	4050	250	" "	4900	100, 340
" "	3410	240	" "	4360	440	" "	5700	390, 530
" "	3460	210	" "	4600	610	" "	6400	110, 530
" "	4240	560	" "	4900	430	" "	6800	110
" "	4700	340	" "	5100	660	" "	6900	*
" "	4900	370	" "	5500	450	" 27	2700	120
" "	5100	540	" "	5700	740	" "	3600	130
" "	5200	*	" "	5800	*	" "	3850	140, 210
" 25	3100	130	" 23	2600	120	" "	4150	140, 340
" "	3200	*	" "	3450	130	" "	4240	150, 760
" "	3370	290	" "	3500	*	" "	4370	150, 600
" "	3600	220	" "	3600	220	" "	5000	120
" "	4250	680	" "	3660	200	" "	5500	120
" "	4400	440	" "	3950	250	" "	6000	110
" "	4800	830	" "	4050	230	" "	6500	130
" "	4900	*	" "	4500	490	" "	7000	130
" "	5300	520	" "	5000	350, 410	" "	7800	220
" "	5500	470	" "	5200	440	" "	8000	*
" "	5700	610	" "	5400	410			
" "	5800	*	" "	5600	650			

*= No value obtained.

Under the general heading of aurora in the Table, the first column gives the character of the day: 0 indicates no aurora; 1, faint; 3, moderate; 5, strong; 7, brilliant; and 9, no observation or no observations possible on account of cloudiness. The second column gives the number of hours during which aurora was present. The third column indicates the amount of sky covered by cloud on a scale of 0-10, where 0 means cloudless, and 10 completely overcast.

Columns four and five describe by letters the form of the aurora, column four indicating forms without ray structure and column five, forms with ray structure. The letters employed are the same as those used in the Photographic Atlas of Auroral Forms published by the International Geodetic and Geophysical Union, Oslo, 1930, so far as it was possible to use those letters. For forms without ray structure *HA* indicates homogeneous quiet arcs; *HB*, homogeneous bands; *PA*, pulsating arcs; *DS*, diffuse luminous surfaces; *PS*, pulsating surfaces; *G*, feeble glow; *HV*, varied forms; *HF*, flaming aurora; and *HVF*, varied forms with flaming. For forms with ray structure *RA* indicates arcs; *RB*, bands; *D*, draperies; *R*, rays; *C*, corona; *RV*, varied forms; *RF*, flaming aurora; and *RVF*, varied forms with flaming.

Column six gives the maximum area of sky covered in tenths of the whole sky, column seven the average altitude in degrees, and column eight the general position of the aurora, being reckoned for included positions in a clockwise direction with *Z* representing zenith and *A* the whole sky. The final column gives the Greenwich mean hour of the observed greatest display in the preceding 24 hours of the Greenwich day.

The table of Kennelly-Heaviside Layer heights is self-explanatory.

Beginning January 1, 1934, the magnetic information for the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, there will be a slight difference in time. Instead of the data covering the 24 hours ending 7 A. M., 105° west meridian mean time, the time covered will be the 24 hours ending at 8 A. M., 75° west meridian mean time, or one hour earlier.

C. C. Ennis

Department of Terrestrial Magnetism,
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PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory
April to June, 1934[1]

(Latitude 57° 03'.0 N., longitude, 135° 20'.1 or 9ʰ 01ᵐ.3 W. of Gr.)

May 18.—The only storm during this period occurred on May 18. After very slight activity in all of the three elements for about five hours, the declination increased quite abruptly at about 7ʰ 51ᵐ, G.M.T. The two intensity-components began at about the same time to decrease slightly, and soon after 10ʰ the rates of decreasing became more rapid. From 12ʰ to 18ʰ all the elements fluctuated through large amplitudes with periods ranging from a few minutes to about two hours. During

this interval the average values of the intensity-components were much less than normal, while the average declination was much greater than normal. At 18^h the fluctuations suddenly ceased. Within a few minutes the declination and the horizontal intensity had returned to their normal values; the vertical intensity became normal in about two hours. The storm ended more suddenly than it had begun. Ranges: Declination, 75′; horizontal intensity, 405γ; vertical intensity, 502γ.

JOHN HERSHBERGER, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY
APRIL TO JUNE, 1934[1]
(Latitude 38° 44′.0 N.; longitude 76° 50′.5 or 5^h 07^m.4 W. of Gr.)

During April 1 to June 30, 1934, magnetic conditions were very quiet. The following days were of character-number "1": April 1, 6, 16, and 30; May 3, 11, 12, 17, and 18; June 5, 6, 8, 12, and 15. A pronounced disturbance occurred May 11 at 20^h to May 12 at 8^h with ranges of 22′ in declination, 147γ in horizontal intensity, and 75γ in vertical intensity.

GEO. HARTNELL, *Observer-in-Charge*

HUANCAYO MAGNETIC OBSERVATORY
APRIL TO JUNE, 1934
(Latitude 12° 02′.7 S.; longitude 75° 20′.4 or 5^h 01.^{m}4 W. of Gr.)

May 18—A minor disturbance began with small undulations in the horizontal-intensity record at 2^h 02^m G.M.T. A sudden increase of about 28γ in horizontal intensity accompanied by an increase of about 5γ in vertical intensity and no perceptible change in declination occurred at 4^h 06^m. At 12^h the horizontal intensity became considerably disturbed, executing large and rapid movements until 19^h which completely obliterated the normal midday increase in that element. Vertical intensity and declination exhibited minor irregular movements during this interval. By 20^h the disturbance had completely disappeared.

J. E. I. CAIRNS, *Observer-in-Charge*

WATHEROO MAGNETIC OBSERVATORY
APRIL TO JUNE, 1934
(Latitude 30° 19′.1 S.; longitude 115° 52′.6 or 7^h 43^m.5 E. of Gr.)

May 18—A minor disturbance began at about 3^h G.M.T., the outstanding feature of which was a sharp movement in all three elements at 4^h 06^m.5. This movement consisted of a sudden increase of about 14γ in horizontal intensity, which increase was maintained for about 20 minutes, and increases of 1′.2 in westerly declination and 5γ in vertical intensity both elements returning to their original values after about two minutes. After the preliminary increase horizontal intensity fell about 120γ to a minimum at 12^h 33^m. The disturbance continued until about 20^h.

W. C. PARKINSON, *Observer-in-Charge*

[1]Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

REVIEWS AND ABSTRACTS

MAURAIN, CH., ET D. LA COUR: *Comptes rendus de l'Assemblée de Lisbonne 17-25 septembre 1933.* Publiés par le Bureau Central de l'Association par les soins de Ch. Maurain et D. la Cour. Bull. No. 9, Association de Magnétisme et Electricité Terrestres, Union Géodésique et Géophysique Internationale. Copenhague, Hörsholm Bogtrykkeri—Hörsholm, 1934 (xi + 354 avec illus.). 24 cm.

The International Union of Geodesy and Geophysics was founded at Brussels in 1919 for the purpose of promoting the study of problems of the shape and physics of the Earth, to initiate and organize researches requiring the cooperation of different countries and to provide for their scientific discussion and publication, and to facilitate special researches such as the comparison of instruments used in different countries. Five general assemblies have thus far been held Rome (1922), Madrid (1924), Prague (1927), Stockholm (1930), and Lisbon (1933). The present volume contains the transactions of one of the Union's seven associations at the Lisbon assembly, namely, that of Terrestrial Magnetism and Electricity. From its perusal may be obtained a good idea of the status of international research in the subjects coming under the jurisdiction of the Association for it contains reports of national committees on geophysical progress and other communications laid before the meetings by the delegates and invited guests from various countries.

In general the form of previous *Transactions* of the Association has been followed, although some necessary changes have been introduced in the arrangement and certain matter has been eliminated to avoid duplication of publication and to decrease expense. The general list of addresses of the members of the Association which appeared at the end of the volumes for the Prague and Stockholm assemblies, has been omitted. It is noted that some of these addresses are appended to reports of the national committees, but in the opinion of the reviewer, it would have been worth the comparatively small additional expense to follow the practice previously adopted and make available a complete revised address-list for reference.

The volume is divided into six parts, the first of which contains the agenda of the meetings, list of delegates and guests present, minutes of the sessions, address of the President, and reports of the Secretary and committee on finance. In his brief address opening the meetings, the President enumerated the losses by death of members since 1930, called attention to the realization of the plans of the Second International Polar Year 1932-33, and stressed the desirability of obtaining continuous records on the ionized regions of the upper atmosphere, the necessity of maintaining suitable secular-variation stations, and the importance of the study of atomic and nuclear physics. The Secretary reported on the progress of matters decided at the Stockholm meeting and rendered an account of the finances of the Association.

In Part II are found the reports of the national committees of 15 different countries, in several of which reports from more that one organization were submitted bringing the total number of reports and communications to 35. The most outstanding event which has found a large place in practically every national report is the preparation and execution of the Polar-Year Program. The international project has lent stimulus to greater scientific effort and activity than would otherwise have been possible under the unfavorable economic conditions prevailing during the last three years. The resulting data will be of inestimable value to research thus justifying the effort put forth. The observations and registrations will not constitute the only lasting results for we learn from the national reports that in certain countries, as for example, Belgium, the observatories established for the Polar-Year work will be made permanent or continued for more or less extended periods of time. On the other hand it is recorded that, owing to financial difficulties, some countries find it impossible to continue on a permanent basis certain stations which would be very desirable from the viewpoint of the world network of observatories.

In Part III are included reports on special topics by committees and reporters appointed at Stockholm. Considerable space is given to the reports of two of these committees the purpose of which is to provide data for advancing our knowledge of the

Earth's magnetism—the committee appointed to consider existing and desirable distribution of magnetic and electric observatories and the better coordination of work and publications of existing observatories, and the special committee on magnetic secular-variation stations. The first-named committee presents a detailed discussion with maps showing the established observatories in 1933 with recommended additions which greatly assists in visualizing the present status of this important question. This report is followed by remarks on new and projected magnetic observatories in the French colonies by the delegate of the French Ministry of Colonies, H. Hubert; and by the report of the sub-committee on the distribution of observatory work in Europe. The second committee presents a tentative list of international repeat-stations with dates of previous occupations and geographic positions also accompanied with maps. To assist in effecting the desired reoccupations of these selected stations, the special committee suggested resolutions (later adopted by the Association) calling upon the governments of all interested countries to participate in assuring adequate determinations of the secular variation at land stations within their borders and urging the desirabliity of finding funds for the construction and maintenance of a vessel similar to the *Carnegie* for resuming the work at sea and on remote islands. The reports on special subjects include: International collaboration to advance the study of the Moon's effect upon geophysical phenomena, by S. Chapman; Ion-counters, methods of use and results, by G. R. Wait; Short preliminary report on three sudden commencements of magnetic storms, by A. Tanakadate; The publication of the numerical magnetic character of days, by G. van Dijk.

Part IV is devoted to the International Polar Year 1932-33. It contains brief reports by C. Störmer on the manufacture and distribution of auroral cameras and by D. la Cour on the manufacture and distribution of auroral spectroscopes. A brief outline on the work of the International Polar-Year Commission completes the section.

Part V, the longest of the sections, contains communications on different subjects. The character and breadth of scope of these communications are apparent from the following brief summary: (*A*) General note and communications from the Department of Terrestrial Magnetism, Carnegie Institution of Washington—Report of the work done by the Department of Terrestrial Magnetism since the Stockholm Assembly, comments on the agenda of the Lisbon meeting, two papers on ionospheric investigations and correlations with geophysical phenomena, numerical magnetic character-numbers, latest annual values of magnetic elements at observatories, photographically enlarged magnetograms for study of sudden commencements, two papers on electric character-numbers, two papers on secular variation, four papers on sudden commencements of magnetic storms, diurnal variation of earth-current potentials on magnetically disturbed and magnetically calm days, and seasonal variation of large ions at Washington, D. C. (*B*) Terrestrial magnetism—Twelve communications with remarks and references, dealing with magnetometers, international catalogue of magnetic determinations, secular change in the United States (180 years of declination, 80 years of horizontal intensity), sudden commencements of magnetic storms (3 articles), numerical magnetic characterization of days, periodic variations in terrestrial magnetism, diurnal component of potential gradient, geology of France as revealed by the new magnetic survey. (*C*) Solar activity—Four papers: Cooperative observations with the spectrohelioscope, by G. E. Hale, to which is appended a table of 23 observatories for which spectroscopes are now available; Methods of recording and measuring solar activity, by J. Bartels; Measurement and methods of observing solar activity, by G. S. da Costa Lobo; and The interval of time between solar phenomena and terrestrial magnetic disturbances, by Ch. Maurain. (*D*) Upper atmosphere, cosmic rays—Two papers: Design of a recording cosmic-ray meter, by A. H. Compton and R. D. Bennett; Work of the Bell System relating to geophysics. (*E*) Atmospheric and terrestrial electricity—Three major papers: Correlation of the Earth's electric field and conductivity of the air, by W. Smosarski; Study of thunder-storms and lightning, by C. Dauzère; Continuous records of point-discharge, by F. J. W. Whipple.

Part VI contains the resolutions, 23 in number, passed at the sessions of the Association, and commissions and reporters for the three-year period until the next General Assembly in 1936. These have already been published in this JOURNAL (**38**, 313-322, 1933).

The volume is of the greatest interest to all who would keep informed on the progress of geophysical research. The reports from the various countries set forth the work accomplished and indicate the problems encountered and the steps taken for their solution. The efforts put forth and the results obtained during the past three years of world-wide depression, have been by no means inconsiderable and no one can fail to observe therein the beneficial and stimulating influence of this great international body whose duty it is to encourage and coordinate the endeavors of all countries to advance

our knowledge of the physics of the Earth and its atmosphere. The records of these world-embracing operations form the subject-matter of the triennial *Transactions* of the Association.

The present volume is somewhat smaller than its predecessor. It is printed in larger and clearer type on an excellent quality of paper. The promptness with which these important contributions of such diverse origin have been brought together, edited, and seen through the press, reflects much credit upon all who had a part in their publication.

H. D. HARRADON

LJUNGDAHL, G. S.: *A magnetic survey of Sweden made by the Hydrographic Service in the years 1928-1930.* Stockholm, Kungl. Sjökarteverket, Jordmag. Pub. Nr. 9, 1934 (37 with 6 pls.). 31 cm. *Punkbeskrivningar till de åren 1928, 1929 och 1930 uppmätta jordmagnetiska sekulärstationerna.* Bilaga till Jordmag. Pub. Nr. 9, 1934 (37 with 12 sheets of photographs).

The investigations described in this publication were carried out under the immediate direction, and in large part by, the author. Assistance in making the observations for declination and inclination was rendered by S. Aslund.

The introduction, setting forth the reason and purpose of the survey together with a brief statement of the scope and plans for the proposed work, is followed by a description of the instruments used, the method of selecting station-sites and testing for local disturbances and the distribution of stations. In the reduction of the observations use has been made of the records from the Danish observatory at Rude Skov and from the Finnish observatory at Sodankylä in addition to those of the Swedish observatory at Lovö. The reduction to normal values was accomplished through the application of the least-square principle expressed in the linear form.

The marked anomalous magnetic conditions existing in Sweden was brought out by the fact that of the eighty-six stations occupied during the three seasons the work was in progress, fifty-three could be classified as "undisturbed" and as being suitable to be included in the computation of normal values. The results of observations obtained each year are reduced to the mid-year period and the final values presented in appropriate tables. A small base-chart shows the distribution of the fifty-three undisturbed stations and a second chart shows the complete list of stations with appropriate legend distinguishing the undisturbed, the somewhat-disturbed, and the highly-disturbed stations.

The results for declination, inclination, horizontal intensity, and vertical intensity are shown graphically by charts giving the computed normal values and expressing the observed values as departures from the normal. Horizontal and vertical intensity disturbances are shown by a vector-chart. A complete list of the stations occupied with a brief description of the geological formation at each is included.

The publication is accompanied by a supplementary pamphlet containing detailed descriptions of stations and azimuths at each, reproductions of sketches and photographs at stations, etc. Each station was permanently marked.

This survey forms an excellent basis for future determinations of secular variation and presents an opportunity for a comparison of secular changes in disturbed and undisturbed areas in close proximity to each other. The care and precision with which the undertaking was planned and executed mark this as a most admirable piece of work and Dr. Ljungdahl, his assistant, and the Hydrographic Service of Sweden are to be congratulated upon its excellence.

J. W. GREEN

SCRASE, F. J.: *Observations of atmospheric electricity at Kew Observatory.* London, Met. Office, Geophys. Mem., No. 60, 1934. (27 with 3 pls.) 31 cm.

The first part of this paper is devoted to a historical account of experiments in atmospheric electricity and a description of methods and instruments employed in the measurements of the potential gradient. In order to properly evaluate atmospheric-electric data, investigators must be acquainted with the methods of observation and the apparatus used. These are consequently given in considerable detail in this review. In the latter portions of the paper, the author gives the results of measurements of potential gradient, air-earth current and atmospheric conductivity, and discusses certain interpretations pertaining to these results.

The potential gradient was first observed at Kew, in 1843 by Francis Ronalds, by means of Volta's scale on straw electrometers, the collector being in the form of a lantern erected 16 feet above the dome of the Observatory. A water-dropping electrograph,

the earliest it is believed in regular operation, was erected in 1861, under Lord Kelvin's personal supervision. The water-dropper was replaced in December 1931 by a polonium collector, which is renewed every six months. Regular control-observations, using a Kelvin portable electrometer with a fuse attached directly to the terminal, were in-troduced in 1898. The disturbing effects of the apparatus and observer were much greater than expected, consequently observations were begun in 1909, using a horizontal bamboo rod with a fuse attached to its outer terminal and connected to the electrometer. An Ayerton-Mather electrostatic voltmeter was substituted in 1923, for the Kelvin electrometer. Absolute observations by means of a Wilson test-plate in connection with an underground laboratory were begun in 1931.

The electrical conductivity of the air, measured by means of a Wilson test-plate connected to a gold-leaf electrometer, was first determined in 1909. The test-plate is kept at zero-potential by means of a compensator and the conductivity is determined by comparing the charge collected during a given period of time, with that collected by the plate when it is exposed to the Earth's field. Until the end of 1930, the apparatus was used on a tripod 1.35 meters high; since 1931 it has been used to measure the con-ductivity at ground-level. The whole of 1931 must be regarded as a transitional year. The conductivity at ground-level was found, on an average, to be about 25 per cent greater than that at the tripod-level, while the potential gradient was found to be only about one-fourth that at the tripod-level. The ratio of conductivity at ground-level to that at tripod-level decreases with increasing values of the conductivity at tripod-level. The ratio also decreases with increasing wind-velocity, but seems to be independent of the value of the potential gradient either at ground- or tripod-level. Tests indicate that the difference in conductivities at ground- and tripod-levels is only apparent, the low value at tripod-level being in some way connected with the non-uniformity of the electric field over the apparatus. The author concludes: "No satisfactory explanation of these effects has so far been found. It is difficult to see how the distortion of the field over the tripod can have any effect on the ionic content of the air flowing past the plate, and it is hardly likely that it can cause any reduction in the mobility of the ions entering the plate." By means of suitable factors, the earlier data on potential gradient, air-earth current, and conductivity have been reduced to what they would have been had they been measured with the test-plate at ground -level.

Tables giving the average value of the conductivity and air-earth current at 15 hours, for various months of the year for each of the years 1909-1931 inclusive, are shown. The results for these years are shown also in the form of curves, together with curves for the potential gradient. The annual curve for the conductivity shows a minimum during the winter months, and a maximum during the summer, while that or the potential gradient is largely opposite in character to that for the conductivity. The curve for the air-earth current shows only minor variations through the year, amounting at most to a few per cent.

Curves showing variations in the annual means of sunspots, potential gradient, air-earth current, and conductivity are given. The author concludes that any con-nection between sunspots and potential gradient is out of the question.

Diurnal-variation curves for the potential gradient are shown and discussed. The potential gradient shows a well marked double oscillation through the day. Maxima occur during the forenoon and evening, while minima occur during the early morning hours and shortly after noon hour. The ratio of the gradient, for corresponding hours, at Kew to that over the Ocean as measured aboard the *Carnegie*, shows a well-marked diurnal variation. A principal maximum occurs at about 9 hours and a secondary maximum at about 22 hours. The chief minimum occurs at about 14 hours, or at a time when the local convection-current is greatest. The chief maximum occurs at a time when the rate of smoke-production is great and the convection is small. Theoretically, this ratio represents the ratio of local resistance of the air to the total resistance of the air between the Kennelly-Heaviside Layer and ground. The characteristics of the curve, therefore, are similar to what would be expected on the basis of known factors tending to produce it. Accordingly the author concludes that the diurnal variation in the po-tential gradient at Kew can be explained as due to the combination of two processes, one of universal origin, which predominates over the Ocean, and the other of local origin, due primarily to the pollution in the atmosphere.

This survey of results of atmospheric studies at Kew, indicates in a few brief paragraphs the various studies that have been carried on there since the introduction of the work, and will be indispensable to any one using the Kew data. The results of the various studies are valuable contributions to the subject of atmospheric electricity.

<div align="right">G. R. WAIT</div>

NOTES

21. *International Council of Scientific Unions*—The International Council of Scientific Unions (formerly the International Research Council) held its first triennial meeting since the adoption of its new statutes during July 8-13, 1934, at Brussels. Dr. N. E. Nörland, who presided in place of Dr. G. E. Hale, absent because of illness, was elected President for the period 1934-1937, and General J. F. Bourgeois, of France, and Marchese Marconi, of Italy, were elected Vice-Presidents. Drs. Pelseneer and Went remain members of the Executive Committee, and Sir Henry Lyons, the General Secretary.

Among the resolutions passed by the Council was one to the effect that the International Polar-Year Commission is deserving of financial aid for further work on the observations already taken. The Council rejected the request of the International Union of Geodesy and Geophysics for study of population problems for admission as a Union under the Council.

The Commission to further the study of Solar and Terrestrial Relationships was reappointed, and another on instruments and methods met to arrange its future procedure.

The General Assembly accepted unanimously an invitation of the Royal Society to meet in London in 1937.

22. *Magnetic work in Little America*—From a radiogram dated at Little America Agusut 4, 1934, from Dr. Thomas C. Poulter, second in command of the Byrd Antarctic Expedition II and chief of the scientific staff, we learn that recording with the magnetograph began on February 12, 1934, and has been continuous since then except for several interruptions during February and March due principally to trouble with the clock. Absolute observations have been made weekly since March 2, 1934. On the return of the Sun it is planned to establish as many magnetic stations as possible in the vicinity of Little America and on the polar plateau above Thorne Glacier. The present position of Little America has been determined with a probable error of 600 feet.

23. *Astrophysica Norvegica*—We have received the first number of a new series of publications issued under the auspices of the Norwegian Academy of Science and Letters at Oslo, and edited by the Institute of Theoretical Astrophysics of the Oslo University. This new series which will be distributed freely to all institutions and individuals who have heretofore been exchanging publications with the University Observatory, will replace the earlier series *Publications from Oslo University Observatory* which closed with the twelfth issue. The first number of the new series contains the third communication by Carl Störmer "On the trajectories of electric particles in the field of a magnetic dipole with applications to the theory of cosmic radiation." In a later number will be given a detailed description of the new Institute which aims at a consolidation of theoretical work in astronomy and astrophysics, cosmical physics and geophysics at the University, all the activities of the observatory being thus transferred to the new Institute.

Correspondence previously sent to the observatory should therefore be henceforth addressed to The Institute of Theoretical Astrophysics, Blinderen, V. Aker, Norway.

24. *New geophysical observatory in Argentina*—We learn from *Ibérica* (June 23, 1934, pp. 5-6) that thanks to the efforts of Mgr. Fortunato Devoto, formerly director of the Astronomical Observatory of La Plata, there is soon to be established in the vicinity of Buenos Aires, a geophysical observatory devoted particularly to the study of atmospheric and telluric electricity, ionization, and radioactivity of the atmosphere. Rev. Ignacio Puig, S. J., sub-director of the Observatorio del Ebro, Tortosa, Spain, has been invited to direct the installation of the projected observatory. En route thither he visited Paris for obtaining the necessary scientific equipment, and at Buenos Aires he intends, moreover, to deliver a number of scientific lectures.

The new observatory will be under the direction of Rev. Juan Rosanas, formerly a collaborator of the Observatorio del Ebro. In addition to the usual meteorological instruments, there will be apparatus for determining the coefficient of dispersion, electrical conductivity of the air, number of ions of both signs, the potential gradient, and earth-currents (two components). At the present there are only four stations con-

tinuously recording earth-currents, namely, Observatorio del Ebro (Spain), Watheroo (Australia), Huancayo (Peru), and Tucson (United States of America). It is the desire of the founders of this new Argentine observatory, which will be the fifth recording earth-currents continuously, to make it a complete center of helio-geophysical observation along the lines of its prototype of the Ebro in Spain.

25. *Personalia—Dr. Adolf Schmidt*, on the occasion of his seventy-fourth birthday, July 23, 1934, was honored by President von Hindenburg, who conferred on him the "Adlerschild des Reiches" in recognition of his outstanding researches in the field of geophysics in general and of terrestrial magnetism in particular.

M. *Ph. Wehrlé* has been appointed director of the French National Meteorological Office in succession to General *E. Delcambre*, who retired on July 1, 1934.

Dr. *Manuel dos Reis* has been appointed director of the Coimbra Observatory, Portugal, on the retirement of Prof. F. M. da Costa Lobo.

Dr. *J. Bartels*, research associate of the Carnegie Institution of Washington and professor at the Forstliche Hochschule, Eberswalde, Germany, arrived in Washington early in August. He will remain at the Department of Terrestrial Magnetism for about three months engaged on research work in terrestrial magnetism.

Professor *Gregory Breit*, of New York University, and research associate of the Carnegie Institution of Washington, has been appointed professor of theoretical physics at the University of Wisconsin.

O. W. Torreson succeeded Dr. *J. E. I. Cairns* as observer-in-charge of the Huancayo Magnetic Observatory in Peru on September 1, 1934. The latter, having completed his three-year term of service at the Observatory, will return to Washington. *W. E. Scott* has been appointed an observer on the staff of the Observatory and left Washington for Peru on September 1, 1934.

Dr. *Bruno Rolf*, senior meteorologist in the Meteorological-Hydrographical Institution at Stockholm (Statens Meteorologisk-Hydrografiska Anstalt), died May 4, 1934, aged 49 yeares. Since 1915 he was in charge of the geophysical work at the Science Station in Abisko, where the magnetic elements have been registered since 1921. He is known to readers of the JOURNAL for articles regarding the work of that Station.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—*Terrestrial and Cosmical Magnetism*

ALEXANIAN, C. L. Établissement de la carte des anomalies de la composante verticale du champ magnétique terrestre dans les Vosges. Paris, C.-R. Acad. sci., T. 198, No. 19, 1934 (1715-1717).

AMERICAN GEOPHYSICAL UNION. Transactions of the American Geophysical Union. Fifteenth annual meeting, April 26, 27, 28, 1934, Washington, D. C., and Berkeley, California, June 20, 21, 1934. Washington, D. C., Nation. Res. Council, June, 1934 (633 with illus.). 25 cm. [These transactions are published in two parts. Part I contains the introduction, and reports and papers presented at the General Assembly and sections of Godesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Oceanography, and Volcanology. Part II contains the reports and papers presented at the meetings of the Section of Hydrology at Washington, D. C. and at Berkeley, California.]

BANGKOK, ROYAL SURVEY DEPARTMENT. Report on the operations of the Royal Survey Department, Ministry of Defense, for the year 1931-32. Bangkok, Printing School, Wat Sangvej (44 with maps and illus.). 29 cm. [Pp. 38-41 contain results of magnetic observations at various points in Siam.]

BERLIN, PREUSSISCHES METEROLOGISCHES INSTITUT. Bericht über die Tätigkeit des Preussischen Meteorologischen Instituts im Jahre 1933. Mit einem Anhang, enthaltend wissenschaftliche Mitteilungen. Berlin, Veröff. met. Inst., Nr. 402, 1934 (118). 25 cm. [Contains reports on the work in atmospheric electricity and terrestrial magnetism at the Potsdam Observatory, pp. 36-41.]

BRÜCKMANN, W. Levé magnétique de la Suisse. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934. (104-105).

CHAPMAN, S. Report on international collaboration to advance the study of the Moon's effect upon geophysical phenomena. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (136-142).

CRICHTON MITCHELL, A. Discussion on methods of numerical magnetic characterisation of days. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (283-285).

De BILT, INSTITUT MÉTÉOROLOGIQUE ROYAL DES PAYS-BAS. Caractère magnétique numérique des jours. Tome IX. Octobre-décembre 1933. Janvier 1932-septembre 1933 (suppléments, errata). De Bilt, 1934 (iv + 31). 24 cm. [Published under the auspices of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.]

De BILT, METEOROLOGICAL AND MAGNETIC OBSERVATORY. Annuaire. Quatre-vingt-quatrième année 1932. B. Magnétisme terrestre. (K. Nederlandsch Met. Inst. No. 98.) Utrecht, 1933 (vii + 24). 34 cm.

DIJK, G. VAN. Rapport sur la publication du caractère magnétique numérique des jours. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (158-161).

DUVALL, C. R. Numerical magnetic character-numbers. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (210-213).

EBLÉ, L. Séparation des différentes formes d'activité magnétique. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (288-291).

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FANSELAU, G. Ueber den funktionalen Charakter der Abhangigkeit der erdmagnetischen Aktivität von den Sonnenfleckenrelativzahlen. (Im Anhang, Bericht Preuss. met, Inst., 1933.) Berlin, Veröff. met. Inst., Nr. 402, 1934 (104-108).

FLEMING, J. A. Report of committee to consider existing and desirable distribution of magnetic and electric observatories and better coordination of work and publications of existing observatories.   C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (107-113).

   Report by the Department of Terrestrial Magnetism, Carnegie Institution of Washington to the Lisbonne Assembly on work done since the Stockholm Assembly. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (171-189).

   Magnetic investigations of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, May 1933 to April 1934.   Trans. Amer. Geophys. Union, 15th Annual Meeting, Pt. I, Washington, D. C., 1934 (177-181).

FLEMING, J. A., AND C. C. ENNIS. Latest annual values of the magnetic elements at observatories. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (213-218).

   Photographically enlarged magnetograms for study of sudden commencements. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (219-221).

GALLO, J. Magnetic observations in the northern states of Mexico during 1933. Trans. Amer. Geophys. Union, 15th Annual Meeting, Pt. I, Washington, D. C., 1934 (183-184).

GREEN, J. W. Preliminary note on the latest secular-change values in the Caribbean area and South America.   C.-R. Assemblée Lisbonne, Union Géod, Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (230-231).

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HAZARD, D. L. Results of observations made at the United States Coast and Geodetic Survey Magnetic Observatory near Tucson, Ariz., in 1925 and 1926. Washington, D. C., U. S. Dept. Comm., Coast Geod. Surv., Ser. No. 569, 1934 (100 with 13 figs.). 27 cm.

   Alaska magnetic tables and magnetic charts for 1930. Washington, D. C., U. S. Dept. Comm., Coast Geod. Surv., Ser. No. 570, 1934 (35 with 4 maps).   23 cm.

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INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS. Union Géodésique et Géophysique Internationale. Association de Magnétisme et Electricité Terrestres. Comptes Rendus de l'Assemblée de Lisbonne 17-25 septembre 1933 publiés par le Bureau Central de l'Association par les soins de Ch. Maurain et D. la Cour. Copenhague, Hörsholm Bogtrykkeri, 1934 (xi + 354 avec illus.).   25 cm. [This publication, reviewed in this number of the JOURNAL, is Bulletin No. 9 issued by the Association (formerly Section) of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics and contains the detailed transactions of the meetings of the Association held at Lisbon in September 1933. Its contents are grouped in the following divisions: (1) Ordre du jour et procès-verbaux, (2) Rapports nationaux, (3) Rapports sur des sujets spéciaux, (4) Année Polaire, (5) Communications sur différents sujets (6) Résolutions, commissions et rapporteurs.]

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LABROUSTE, M., ET MME. H. Contribution à l'étude des variations périodiques du magnétisme terrestre. . (Composante diurne et semi-diurne de la déclinaison.) C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (292-295).

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Punktbeskrivningar till de åren 1928, 1929 och 1930 uppmätta jordmagnetiska sekulärstationerna. Stockholm, Kungl. Sjökarteverket, Bilaga till Jordmag. Pub. Nr. 9, 1934 (37 med 12 blad fotografier), 31 cm.

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MAURITIUS, ROYAL ALFRED OBSERVATORY. Annual report of the Royal Alfred Observatory for the year 1932. (N. R. McCurdy, Director.) Port Louis, R. W. Brooks, Govt. Printer, 1933, 9 pp. 25 cm. [Contains brief report of magnetic work and gives the mean values of the magnetic elements for 1932.]

Results of magnetical and meteorological observations for the months of January to June, 1933 (new series, v. 19, pts. 1-6). Port Louis, R. W. Brooks, Govt. Printer, 1933 (iv + 1-107).

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NIPPOLDT, A. Die Reichweite einer magnetischen Normalstation. Beitr. angew. Geophysik, Leipzig, Bd. 4, Heft 3, 1934 (302-315). [Bei der im Vergleich zur Ausdehnung der Länder grossen Entfernung zwischen den Stationen einer magnetischen Landesaufnahme müssen die einzelnen Stationen den Wert von Normalstationen haben. Um die Normalität einer Feldstation zu prüfen, wird vorgeschlagen, über alle Dreiecke zwischen benachbarten Punkten das Kurvenintegral zu bilden und es grundsätzlich der Null gleichzusetzen; es wird also angenommen, dass es potentiallose magnetische Felder nicht gebe. Auf diese Weise erhält man die Normalität in bezug auf die horizontalen Elemente. Für die vertikalen prüfe man die Einzelstation durch Lokalvariometer in der nächsten Umgebung jeder Feldstation.]

ONO, S.   Preliminary report of the Second Polar Year observations on terrestrial magnetism and earth potential gradient at Simoda, August 1932-June 1933. C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (76-82).

PATTON, R. S.   Magnetic work of the United States Coast and Geodetic Survey, April 1933 to March 1934.   Trans. Amer. Geophys. Union, 15th Annual Meeting, Pt. I, Washington, D. C., 1934 (182-183).

PARIS, BUREAU DES LONGITUDES.   Annuaire pour l' an 1934 avec des notices scienti-fiques. Paris, Gauthier-Villars (vii $+$ 480 $+$ A.15 $+$ B.6 $+$ C.12 $+$ D.27 $+$ E.50). 20 cm. [Contains isogonic charts of France for epoch January 1, 1931 and tables of magnetic declination at various stations in France reduced to same epoch.   A table of mean annual values for observatories in all parts of the world is also given. On pages 417-418 is a brief sketch on atmospheric electricity.   "Les services rendus par le Portugal aux sciences géographiques" by Ch. Lallemand, and "La Cinquième Assemblée Générale de l'Union Géodésique et Géophysique Internationale à Lisbonne, septembre 1933" by G. Perrier, appear among the Scientific Notices.]

PARIS, INSTITUT DE PHYSIQUE DU GLOBE.   Annales de l'Institut de Physique du Globe de l'Université de Paris et du Bureau Central de Magnétisme Terrestre.   Publiées par les soins de Ch. Maurain.   Tome XII.   Paris, Les Presses Universitaires de France, 1934 (iii$+$86 avec 4 pages de graphiques).   31 cm.   [A signaler: L. Eblé— Observations magnétiques faites au Val-Joyeux pendant l'année 1932; E. Tabesse— Observations magnétiques faites à l'Observatoire de Nantes pendant l'année 1932; E. Salles—Observations du champ électrique au Val-Joyeux pendant l'année 1932; Ch. Maurain—Sur l'intervalle de temps entre les phénomènes solaires et les per-turbations magnétiques terrestres;   P. Charczenko—Mesures de la susceptibilité magnétique de quelques minéraux et de quelques roches basiques;   M. et Mme. H. Labrouste—Composantes diurne et semi-diurne de la déclinaison et agitation mag-nétique;   Principales perturbations magnétiques en 1932 (graphiques obtenus aux enregistreurs de Val Joyeux).]

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PETERS, W. J., AND C. C. ENNIS.   Note on sudden commencements, October 14, 1932, and April 30 and May 29, 1933.   C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, Copenhague, 1934 (244-247).

REICH, H.   Zur Säkularvariation der Vertikalintensität in Deutschland für die Zeit von 1901 bis 1931.   (Vorläufige Mitteilung.)   Beitr. angew. Geophysik, Leipzig, Bd. 4, Heft 3, 1934 (373-384).   [Es wird an Hand eines Zahlenmaterials, das durch Variometermessungen erhalten wurde, gezeigt, dass die säkulare Aenderung von Z in Deutschland für die Zeit von 1901 bis 1931 auch nicht angenähert durch eine lineare Gleichung dargestellt werden kann.   Das erhaltene Z-Isoporen-Bild zeigt deutliche Beziehungen zu den geologischen Grossstrukturen.]

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B—*Terrestrial and Cosmical Electricity*

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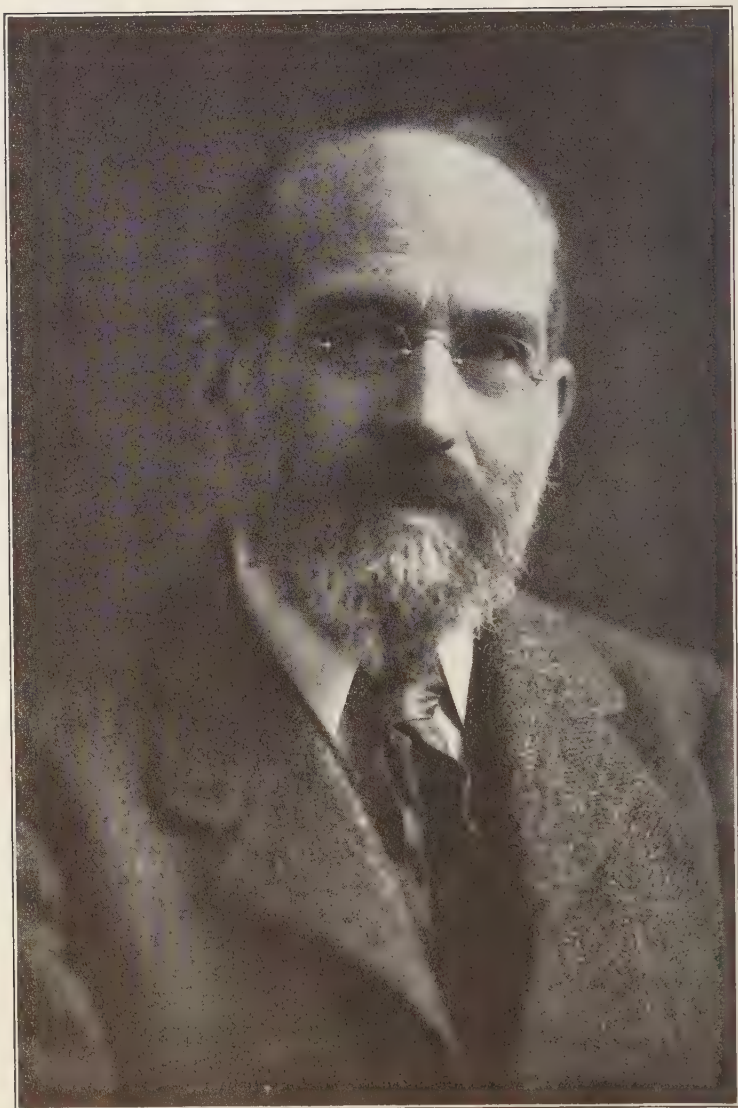
[Plate 4]

Yours truly
Arthur Schuster

ON THE ORIGIN AND MAINTENANCE OF THE SUN'S ELECTRIC FIELD

BY ROSS GUNN

Abstract—The systematic motion of the Sun's conducting atmosphere across its own magnetic field is shown to modify greatly the effective electrical conductivity of the region. The velocity of the superposed mass-motion of the atmosphere due to the impressed crossed electric and magnetic fields is found to be E/B to a very good approximation. It is shown that the processes of ionization and recombination of ions and electrons subject simultaneously to impressed electric and magnetic fields result in a systematic migration of the ions. The greater probability of electrons recombining when they possess a minimum of energy results in a transport of charge in a direction opposite to the motion imposed by electrical conduction. The magnitude of this systematic motion in the Sun is adequate to replenish the Sun's electric charge and hence maintain a steady electric field.

Electrical equilibrium in the reversing layer is determined by "three-body" recombinations and the electronic conductivity, whereas equilibrium in the chromosphere is determined by "two-body" recombinations and the ionic conductivity. The latter equilibrium is of such a type that high effective electron-temperatures must exist in the chromosphere and this is adequate to explain both the presence of certain solar bright-line spectra such as the ionized helium line λ 4868 and the observed chromospheric pressure-gradients. The estimated effective temperature of the chromospheric ions approximates 26,000°.

The superposed atmospheric velocity and electric fields calculated from the present theoretical considerations agree in magnitude, direction, and distribution with those deduced in earlier papers from observational data regarding the anomalous solar rotation [Phys. Rev., **35**, 635-642 (1930), and **36**, 1251-1256 (1930)].

The discovery more than two decades ago of a general solar magnetic field having many properties analogous to those of the terrestrial-magnetic field led astrophysicists to suppose that the Sun possesses an electric field much like the Earth's. Indeed, Hale and Babcock[1] sought evidence of such a field and showed that if it existed its magnitude could not exceed 100 volts/cm. Some years later Pannekoek[2] calculated that a typical star in gravitational equilibrium might have a very small *outward* electric field amounting to something less than 10^{-7} volts/cm.

In a series of papers[3] the author has examined some of the effects that might be expected to result from the motion of ions in the Sun's atmosphere. It was shown that the forces acting on the constituent ions were such as to produce systematic motions which explained satisfactorily several remarkable and puzzling solar phenomena. For ex-

[1] Proc. Nation. Acad. Sci., **1**, 123-127 (1915).

[2] Bull. Astr. Inst. Netherlands, **1**, 110 (1922).

[3] Phys. Rev., **35**, 635-642 (1930); **37**, 983-989, 1129-1134 and 1573-1578 (1931); also Science, **76**, 577-583 (1932).

ample, it was noted that the principal characteristics of the Sun's anomalous rotation were readily describable if an electric field were postulated which has the following properties:

(1) The electric field is nearly everywhere radially *inward* (that is, has the same direction as the normal terrestrial-electric field) and substantially perpendicular to the observed solar magnetic field. A typical calculated value for the field in the reversing layer is 0.013 volts/cm, (see Fig. 1 which is calculated from the observational data).
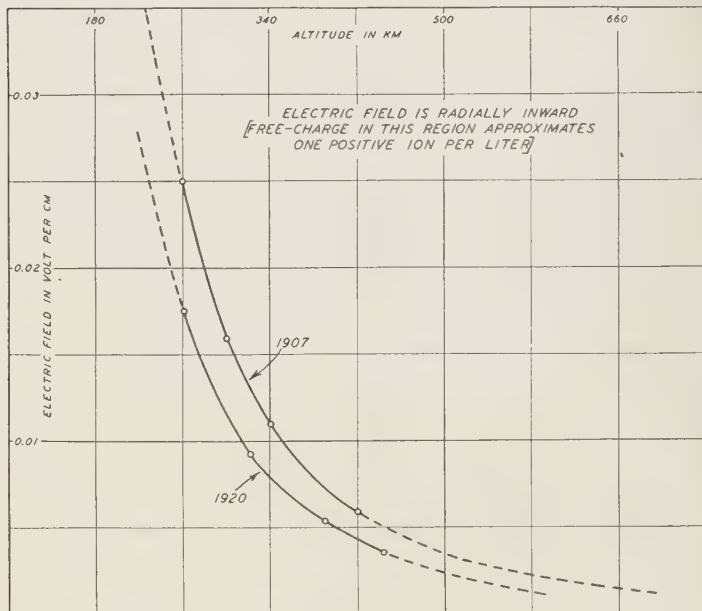
FIG. 1

(2) The electric field decreases with decreasing pressure (increasing altitude) in such a way that the ratio of the electric to the magnetic field-intensity is roughly constant within the reversing layer and increases slowly above it.

(3) In observed regions probably not more than one ion in 10^{14} is a free ion and hence the atmosphere departs but slightly from strict neutrality.

(4) The ratio of the electric to the magnetic field-intensity at given points is a function of solar activity.

These properties of the electric field and the derived numerical data seem to provide a sufficiently detailed foundation upon which one may build an adequate theory of its origin and maintenance. In the present paper we direct our attention to the underlying physics and will work out in a rough quantitative manner the expressions for the con-

duction and replenishing current-densities which in any steady state must balance each other. We consider a mechanism whose proper interpretation leads to the conclusion that the Sun's atmosphere is pervaded by electric fields of just the required type and magnitude to account for the observed anomalous solar rotation and the excessive excitation of ions and atoms in the chromosphere.

ION-MOTIONS AND CONDUCTION-CURRENT

In earlier papers we gave sound reasons for supposing that the Sun proper is quasi-rigid and rotates on its axis with a period identical with the period of rotation of its magnetic poles or 31.8 days. This quasi-rigid structure is taken as the basic reference system, and hence an observer in this system would witness superposed eastward winds throughout the entire atmosphere which will be attributed to a radially inward electric field and a northerly magnetic field.[3]

The usual expressions for electrical conductivity assume that the ionized gas is at rest and that the mean initial velocity of the ions at the beginning of each free-path is effectively zero. Obviously, this is incorrect when applied to the Sun's atmosphere for the ion gas and the associated neutral atoms are both in motion. We may calculate the conduction-current either by employing the proper mean initial velocity of the ions after collision and determine an *effective* conductivity, or we may use the conductivity of a gas at rest and note that the gas moving across the Sun's magnetic field will set up a reversed secondary electric field which is nearly as great as the impressed one. Thus, the effective field acting on each ion is greatly reduced. In the following discussion we employ the first method because it is the more direct. Electromagnetic units are used throughout.

A set of coordinates is chosen in the Sun's atmosphere such that the positive Z-axis is directed along the magnetic field B which is northward at the equator, the positive Y-axis is radially outward and coincides with an impressed electric field E, while the positive X-axis is directed toward the west. The equations of motion of an ion in the presence of these crossed fields are

$$(\mathrm{d}^2x/\mathrm{d}t^2) = (Be/m)\ (\mathrm{d}y/\mathrm{d}t) \tag{1}$$

$$(\mathrm{d}^2y/\mathrm{d}t^2) = Ee/m - (Be/m)\ (\mathrm{d}x/\mathrm{d}t) \tag{2}$$

$$(\mathrm{d}^2z/\mathrm{d}t^2) = 0 \tag{3}$$

where e is the ionic charge and m is its mass. Setting $-\omega = Be/m = V/\rho$ where ρ is essentially positive and is the radius of the spiral generated by the moving ion and V is the component of its velocity perpendicular to the magnetic field B; then upon integration the impressed velocity-components are

$$(\mathrm{d}x/\mathrm{d}t) = E/B + [V_{ox} - E/B]\ \cos\omega t - V_{oy}\ \sin\omega t \tag{4}$$

$$(\mathrm{d}y/\mathrm{d}t) = [V_{ox} - E/B]\ \sin\omega t + V_{oy}\ \cos\omega t \tag{5}$$

$$(\mathrm{d}z/\mathrm{d}t) = V_{oz} \tag{6}$$

where V_{ox}, V_{oy}, and V_{oz} are the component initial velocities of the ion along the X-, Y-, and Z-axes, respectively. It is clear from these expressions that if the mean free-path is indefinitely long, the ions move

along only the X-axis with a mean drift-velocity $u = E/B$ and have no net motion whatever in the direction of the electric field.

In general the ions will collide, and by assuming that the thermal velocities V of all the ions of a given kind are identical, we can readily determine the mean impressed drift-velocity. If λ is the mean free-path, the mean interval between collisions is λ/V, and the probability of an ion having a flight-time between t and $(t+dt)$ is $(V/\lambda) \exp [(-V/\lambda)t]dt$. Thus, since the collision-frequency or V/λ is nearly independent of the velocity of the superposed mass-motion, the absolute values of the mean drift-velocities $\overline{V}_x$ and $\overline{V}_y$ are given approximately by

$$\overline{V}_x = (E/B)\int_0^\infty (V/\lambda) \exp [(-V/\lambda)t] \ dt + [V_{ox} - (E/B)]\int_0^\infty (V/\lambda) \\ \exp [(-V/\lambda)t] \cos \omega t \ dt \qquad (7)$$

$$\overline{V}_y = (V_{ox} - E/B)\int_0^\infty (V/\lambda) \exp [-(V/\lambda)t] \sin \omega t \ dt \qquad (8)$$

where we have assumed, quite properly, that the mean initial velocity V_{oy} of the colliding ions in the direction of the electric field is approximately zero. Upon integration these equations yield

$$\overline{V}_x = (E/B) + [\overline{V}_{ox} - (E/B)] \left\{ 1/[1 + (\lambda/\rho)^2] \right\} \qquad (9)$$

and

$$\overline{V}_y = [\overline{V}_{ox} - (E/B)] \left\{ (\rho/\lambda)/[1 + (\rho/\lambda)^2] \right\} \qquad (10)$$

where $\overline{V}_{ox}$ is the mean initial velocity of the ions after collision.

The electric field in the Sun's atmosphere is radially inward and E negative so that (9) predicts eastward ion-velocities in long free-path regions of magnitude $E/B = u$. Further, since all terms of (9) are independent of the charge on the ion, both positive and negative ions move in the same direction and hence constitute a mass motion.

Recent investigations, particularly those of Russell[4] and of Menzel[5] indicate that the atomic density at the *base* of the reversing layer is about 6×10^{15} atoms/cc and the electron-density is about 7×10^{13} electrons/cc. The major part of the atomic density according to these investigations is probably due to hydrogen which is but slightly ionized. We shall see presently that the number of collisions between ions and neutral atoms is as great as the number of collisions between ions and other ions so that the interchange of momentum between the two groups is considerable and the neutral particles partake of the superposed systematic ion-motions. It is not considered that the neutral particles actually travel to the eastward with precisely the same velocity as the ions because the viscous forces produce a slight drag which decreases with increasing altitude. With the entire atmosphere in systematic motion it is clear that after each collision the mean initial velocity of the next free-path is no longer zero but will approximate E/B; the exact departure being dependent upon the viscous forces acting and hence the effective altitude of the layer under consideration. Thus the second term of (9) is normally small compared to the first and the superposed drift-velocity $\overline{V}_x$ is therefore relatively insensitive to the magnitude of λ/ρ, un-

[4] Astroph. J., **70**, 11-82 (1929).
[5] Pub. Lick Obs., **17**, 1-303 (1931).

til the pressure and velocity space-gradient become quite large very near the photosphere. It is therefore concluded that the ionic drift-velocities of both kinds of ions closely approximate $E B$ throughout the visible regions of the Sun's atmosphere. Indeed observation demands that this must be true, because an appreciable difference in drift-velocity between the electrons and the heavy positive ions (which are little affected by the magnetic field and will share to a close approximation at least the velocity of the equally massive neutral atoms) would imply tremendous systems of electric currents and their associated magnetic fields for which there is no observational evidence. Numerical values for the difference in drift-velocities of the positive and negative ions are readily estimated. From Ampere's law we have very approximately that the current-density is given by

$$i_x = (1/4\pi)(dB_z/dy) \tag{11}$$

and since the electrons will take up the maximum drift-velocity at higher pressures than the positive ions, the direction of the current-flow will be opposite to the mass-motion. The resulting current-density cannot greatly exceed that given by (11) if we employ the observed value for (dB/dy) which approximates 7.0×10^{-6} gauss/cm in the lower reversing layer. Thus the permissible current-density cannot exceed 6×10^{-7} e.m.u./cm^2 and if the ion-density n is something like 7×10^{13} ions/cc, then the mean difference in the drift-velocities or $(V_{ox} - u)$ is not likely to exceed i/ne or 0.6 cm/sec in any observed region. It is therefore clear by (9) that $E B$ gives the mean superposed mass drift-velocity with greater precision than our calculations in earlier papers indicated. The relation breaks down badly only when the associated ions and neutral atoms transfer momentum to nearby more slowly moving regions faster than they can acquire it from the electric field.

The conduction current-density i_y parallel to E, which we recall is transverse both to the direction of the ion-drift and the magnetic field, is, by (10)

$$i_y = ne\overline{V}_y = neb\rho/\left\{ \lambda[1 + (\rho/\lambda)^2] \right\} = [(\overline{V}_{ox}/u) - 1]\left\{ ne\rho E/B\lambda[1 + (\rho/\lambda)^2] \right\} \tag{12}$$

where $b = (\overline{V}_{ox} - E B)$ and, as we have seen, is of the order of magnitude of 1 cm/sec or less. Hence, since the bracketed term is very small, the effective conductivity of the region is small and approaches zero as the motion of the neutral atoms and positive ions approaches $E B$. Clearly, (12) may be written

$$i_y = [\overline{V}_{ox}B - E]\left\{ ne\rho/B\lambda[1 + (\rho/\lambda)^2] \right\} = \sigma_0 E_f \tag{13}$$

so that we might equally well have used the ordinary electrical conductivity $[i_y E$ of (12) when $\overline{V}_{ox} = 0]$ for calculating i_y if an effective electric field, E_f, which is the difference of the impressed and a motional electric field, were substituted for E. It is clear that the total current-density is determined by summing up terms like (12) or (13) for all types of ions present in the region.

We shall now put (12) in a more convenient form. The mean free-

path λ of a particle is given to a near enough approximation for the present purpose by the familiar relation

$$\lambda = 1/[(2)^{1/2}\pi d^2 n_1] \tag{14}$$

where d is the effective collision-diameter and n_1 the atomic density. The effective collision-diameter of neutral hydrogen is but 2×10^{-8} cm while that of two colliding ions which are deflected $90°$ on the average is $d = 2c^2e^2/3kT$ or about 1.85×10^{-7} cm. Thus, for a given mean free-path, neutral hydrogen may be 85 times as abundant as the coexisting ions. This is about the estimated ratio in the Sun's atmosphere and it is convenient therefore to consider only the collisions between ions and ignore collisions between neutral atoms or neutral atoms and ions since these collisions cannot affect the order of magnitude of the calculated result. Substituting the electrical collision-diameter for d in (14), then (12) becomes

$$i_y = \sum \frac{Abm^{1/2}n^2}{B[1+(A^2mn^2 B^2e^2)]} = \sum \frac{Am^{1/2}[(\overline{V}_{ox}/u)-1]n^2E}{[1+(A^2mn^2 B^2e^2)]B^2} \tag{15}$$

where

$$A \equiv 4\pi(6)^{1/2}c^4e^4/9(kT)^{3/2}$$

and n is the ionic density. By the use of this relation we calculate the radial current-density at the "base of the reversing layer" where the electronic and ionic densities are 7×10^{13} ion cc. Adopting 10^{-27} gm for the mass of the electron, 5×10^{-24} gm for the mass of the mean ion, taking $B = 50$ gauss and $T = 6000°$, it is found that the second terms of the bracketed expression in the denominator are 0.4 and 1200, respectively, showing that on the average the electrons describe nearly complete spirals around the magnetic field between collisions, whereas the heavier ions are little affected by the magnetic field. Adopting further the deduced value of $b \leq 0.6$ cm sec, the current-densities according to (15) are

$$\left.\begin{array}{l} i_y \text{ (electrons) } \leq 4.0\times10^{-7} \text{ e. m. u./cm}^2 \\ i_y \text{ (ions) } \leq 2.8\times10^{-8} \text{ e. m. u./cm}^2 \end{array}\right\} \tag{16}$$

The electric field in the region where $B = 50$ gauss is 2.5×10^6 e. m. u. so that the effective conductivity σ_{oy} of the moving ion-layer approximates 10^{-13} e. m. u.

It is of considerable importance to note that the effective conductivity of the Sun's atmosphere is non-isotropic. Equations strictly analogous to (10) show that since $\overline{V}_{oy}$ is essentially zero the mass motions parallel to E_x will not change σ_x from its rest-value. Further, it is clear that the magnetic field has no influence on the conductivity along it, so that in regard to order of magnitude, at least in the equatorial regions of the lower reversing layer, we may write $\sigma_x:\sigma_y:\sigma_z = 0.6:10^{-5}:1$. Hence any excess of charge delivered to a localized region is readily conducted to nearby regions *at the same level*. Conduction from one level to another, however, is relatively slow.

Fluctuating electric fields and rectification in the solar atmosphere

Assume for a moment that the Sun's atmosphere is quite free of electric fields and that its observed magnetic field is undisturbed. Then if any large-scale turbulence is developed, it is quite clear that the highly conducting atmosphere will in many cases be swept across the impressed magnetic field and an electric field generated thereby. The magnitude of the motional field E is

$$E = vH \qquad (17)$$

where H is the component of the impressed magnetic field-intensity that is perpendicular to the velocity v. At the solar equator, for example, an eastward motion will produce a radially outward field and a westward motion an inward field. Motions along the magnetic field, of course, contribute nothing. Generated electric fields of this type must play an important part in determining the turbulent state of the Sun's atmosphere because without their protecting (and propagating) influence the individual ions would be constrained to spiral about the magnetic field in the same place where they last collided. However, with a large excess of neutral atoms these considerations require modification.

Turbulent motions in the Sun's atmosphere having a mean velocity of some kilometers per second are often observed so that we may be sure that random electric fields of the magnitude given by (17) actually exist, (that is, fields approximating 0.05 volts cm). In another place it has been shown that the Earth's atmosphere has electrical rectifying properties such that random electric fields due to thunder-storms transfer negative charges to the surface of the Earth and that this transfer is great enough to account for the observed fair weather air-earth current[7]. The Sun's atmosphere also has rectifying properties but not to such a marked degree. By assuming that the turbulent motions are nearly independent of altitude and that the magnetic field may be expressed by the empirical relation $H = H_0 \exp(-az)$ it can be shown following the earlier argument[7] that the mean rectified current-density transferred from the surface of the Sun proper is

$$i_R = \sigma_0 a v^2 H^2 / 8\pi n e c^2 \qquad (18)$$

This current-density is positive and in such a direction as to make the surface of the Sun negative. Substitution of numerical values shows that i_R is much too small to account for the *maintenance* of the solar charge but the mechanism does suggest why the solar and terrestrial fields are both *radially inward*. The presence of such a small initial field seems of some qualitative importance because we will show in the next section how a small initial and radially inward field can increase in magnitude until equilibrium is established. The equilibrium-values for the resulting fields are in satisfactory agreement with those inferred from our earlier calculations.

Electrical currents resulting from ionization and recombination

The process of ionization and the converse effect of recombination play an important rôle in stellar atmospheres. In the present section we

[7]R. Gunn, Terr. Mag., **38**, 303-308 (1933).

show that recombination-probabilities of ions immersed in crossed electric and magnetic fields are systematically modified in such a manner that the recombining electrons move preferentially against the electric field and with an average velocity sufficient to account for the observed solar current.

Recombination takes place in two general ways: First, by three-body collisions which we will describe as "J. J. Thomson recombinations"; and second, by spontaneous recombinations which are essentially two-body collisions. The number of ions recombining per unit-volume per unit-time is given by

$$(\mathrm{d}n/\mathrm{d}t) = -an_+n_- = -an^2 \equiv N \tag{19}$$

where n is the density of ionic pairs and a is the recombination-coefficient. Physically, a is the volume swept out by an ion's recombining area per unit-time whence $a = qv$ where q is the effective recombination cross-section and v the mean ionic velocity. It is clear, therefore, that in a gas composed of ions and electrons the electrons, because of their far greater speed, predominately determine the rate of recombination. We therefore may ignore the part played by positive ions in this section. The recombination-coefficient for electrons at low pressure according to J. J. Thomson's formula is

$$a_t = 4\pi v_e d^3/\lambda_e \tag{20}$$

where v_e and λ_e are respectively the velocity and free-path of the electron and d is the electrical collision-diameter, or c^2e^2/W, where W is the kinetic energy of the electron. Substituting and employing (14) we have that the Thomson collision-area is

$$q_t = (4)\ 2^{1/2}\pi^2c^{10}e^{10}n/W^5 \tag{21}$$

whereas the spontaneous capture collision-area is approximately[8]

$$q_s = 10^8q_oe/W \tag{22}$$

where q_o has been taken arbitrarily as the effective cross-section for one-volt electrons and approximates 10^{-21} cm². Upon setting $W = 3kT/2$ it is found that $q_t = q_s$ when $n \doteq 10^{11}$ ions/cc. Thus, Thomson recombinations are important in the reversing layer while spontaneous recombinations predominate above it. Since most of the moderately reliable data apply to the reversing layer, it will be convenient to carry through most of the calculations employing only q_t.

The probability that an electron will be captured is clearly proportional to the collision-area which according to (21) or (22) is inversely proportional to the kinetic energy of the ion, W. Thus if forces act continuously on an electron in such a way that W is decreased or increased the chance of neutralization is correspondingly increased or decreased. It was noted in an earlier paper that electrons in the solar atmosphere describe cycloidal paths and that during the description of a free-path they take on and lose, successively, considerable energy.

The mean energy added or subtracted is[3]

$$\triangle W = mvu[1 + (u/v)^2]^{1/2} \tag{23}$$

[8]E. C. G. Stueckelberg and P. M. Morse, Phys. Rev., 36, 16-23 (1930).

so that the ratio of the added energy to the initial mean kinetic energy is

$$\triangle W/W_t = (2u/v)[1+(u/v)^2]^{1/2} \doteq (2u/v)_{electron} \tag{24}$$

where W_t is the mean initial or thermal energy of the ion. Now if $\triangle W$ is positive and equal to W_t then $W = 2W_t$ and according to (21) and (22) the effective collision-area is much less than its mean value; however, if $\triangle W$ is negative and equal to W_t it is clear that $W = 0$ and the probability of recombination of the electron becomes unity. Thus it appears that the probability of recombination of an electron varies continuously and systematically as it describes its cycloidal path in the Sun's atmosphere and that recombination occurs preferentially in certain parts of the trajectory, namely, in those parts where the electron's kinetic energy is near its minimum. It is assumed that the mean initial energy of the electron immediately after collision is a constant and equal to $3kT/2$, and that the *mean* recombination is determined by the thermal energy alone.

The equations of motion show that an electron moves periodically with and against the impressed electric field but on the average advances along it only by collisions. The component of the maximum displacement along the electric field is evidently the diameter of the cycloidal generating circle or 2ρ. At the "top" of an electron-path a typical electron has gained an excess energy $eE\rho$ and at the "bottom" of its path it has lost a similar amount. [Substitution of the value for ρ leads to (23)]. Thus it is clear that in the presence of a *radially inward* impressed electric field, less than the average number of recombinations take place when the ion is at the top of its path and more than the average occur at the bottom of its path. Thus a preferential transfer of negative charge toward the Sun's surface takes place and is in the correct direction to replenish the charge carried off by the conduction-current.

Let $\triangle N$ electrons per unit-volume per unit-time recombine at points, distant $K\rho$ "above" (measured in the direction of $-E$) the point of their last collision; then the transport current-density i_t is

$$i_t = -\triangle NeK\rho \tag{25}$$

where K is a constant of the statistics and is something less than unity.

We have further that

$$\triangle N/N \doteq \triangle q/q = -\eta(\triangle W/W) \doteq -(2\eta u/v) \tag{26}$$

where N is the total number of recombinations per unit-volume per unit-time, $\triangle q$ the change in recombination-area due to a given energy-change in the electron of $\triangle W$ and η lies between 5 and 1, its value being dependent upon the relative importance of the Thomson and spontaneous recombinations.

Thus combining (19), (24), (25), and (26) and ignoring $(u/v)^2$ because of its small value compared to unity, we have

$$i_t = 2K\eta e\rho u[q_t+q_s]n^2 \tag{27}$$

2

Introducing the value of ρ and expressing the mean velocity in terms of temperature we have, finally, that the transport current-density is given by

$$i_t = -2K\eta(3m_e kT)^{1/2}[\varrho_t + \varrho_s](n^2 E/B^2) \tag{28}$$

This current flows against the impressed electric field and hence replenishes the charge carried off by conduction. In the lower reversing layer we take $K = 0.5$, $\eta = 5$, $m_e = 9 \times 10^{-28}$ gm, $T = 6000°$, $W = 3kT/2$, $n = 7 \times 10^{13}$ ions/cc, $B = 50$ gauss, and $E = 2.5 \times 10^6$ e. m. u./cm, from which data we calculate $\varrho_t = 1.2 \times 10^{-18}$ and $i_t = 13 \times 10^{-7}$ e. m. u./cm². Thus it appears that the processes of replenishment are *more than sufficient to maintain the conduction current-density* calculated by (15) and (16). We now proceed to show that the electric field is regeneratively built up by the foregoing processes until the effective temperatures of the atmospheric layers are sufficiently increased by dissipation-processes to bring about a modification of the recombination-rate and the effective conductivity and hence, stability.

Electrical equilibrium and effective electron-temperatures

Since in any *steady state* the conduction and replenishing current-densities must be equal, we may write from (15) and (28) that

$$\sum \frac{4\pi 6^{1/2} c^4 e^4 m^{1/2}[(\overline{V}_{ox}/u) - 1]}{9(kT_e)^{3/2}[1 + 96\pi^2 c^3 e^3 mn^2/81 B^2 e^2(kT_e)^3]} = \\ 2K\eta(3mkT_e)^{1/2}\left[\frac{4\pi^2 2^{1/2} c^{10} e^{10} n}{[(3/2) kT_e]^5} + \frac{10^8 q_o e}{(3/2) kT_e}\right] \tag{29}$$

where the left-hand expression is summed up over all types of conducting ions and T_e is now the effective temperature of the ions or electrons. It is well known from studies of the discharge-tube that conduction and dissipative processes bring about a redistribution of the ionic energies and the resulting effective electron-temperature may considerably exceed that of the associated atoms. Electrical conduction-processes in the Sun result in an entirely similar situation and, indeed, it appears that stability of the electric field is determined primarily by the increase in effective temperature of the conducting and recombining electrons.

Throughout the lower reversing layer Thomson recombinations determine the magnitude of the replenishing current and this type of recombination is quite sensitive to an increase in the effective electron-temperature. Moreover, since conduction in this region is primarily due to electrons we may approximate (29) and write

$$(T_e^3/u)_{Reversing\ layer} = 64\pi Kc\eta^6 e^6 n/27k^3 b \tag{30}$$

Adopting, as before, $n = 7 \times 10^{13}$, $K = 0.5$, $\eta = 5$, and $b = 0.6$ cm/sec, it is found that $BT_e^3/E = 9.6 \times 10^6$. Observation shows that the effective temperature of the reversing layer does not greatly exceed $6000°$ and thus $u = E/B$ approximates 2.2×10^4 cm/sec. This is considered to be in agreement with the earlier estimate of 5×10^4 cm/sec because of the unreliability of the data and the approximations introduced. If T_e is

taken to be 7800° the agreement is exact. There is little doubt that b decreases with increasing altitude much as n is known to decrease; thus u approximates the above calculated constant throughout the reversing layer. It will be recalled that our original estimates of the electric field were based on this assumption and hence the present calculated values of E necessarily agree in magnitude and distribution with those estimated from the facts of the anomalous rotation.

It was concluded in an earlier paper[9] that the velocity of the super-posed eastward electromagnetic winds would be a function of the flux of radiant energy traversing the layer. The conclusion is verified by our theory since by (30), u is proportional to T^3_e and hence is very sensitive to changes in effective temperature. Thus since the Sun's radiation is not constant, a spread in the calculated values similar to that of Figure 1 is to be expected.

Spontaneous recombinations control the replenishment processes in the chromosphere and reference to (29) shows that the electron-con-ductivity in this region decreases with increasing temperature more rapidly than do the replenishing recombination-effects. This suggests that the electric field will increase without limit as indeed it might, were it not for the conduction due to the heavier ions. It is therefore proper to calculate the current-density, roughly at least, by considering the ions alone. If we adopt the chromospheric ion-densities estimated by Menzel[5] (10^{11} ions/cc at its base), then it follows that the heavy positive ions which are equally as numerous as the electrons will not spiral freely around the impressed magnetic field and hence the second term of the denominator on the left side of (29) will be large compared to unity. It now becomes necessary to distinguish carefully between the effective temperature of the ions T_i and that of the electrons T_e. We assume that in the chromosphere $T_i = pT_e$ where p is something less than unity and amounts (as inferred from the work in discharge-tubes by Langmuir) to perhaps 0.7. Making the appropriate approximations and this time considering only the spontaneous recombinations it is found that

$$(T_e^2/u) \ _{Chrom.} = (2^{1/2}16\pi 10^8 q_o K \eta c^4 e^3 m_e^{1/2} m_i^{1/2}/9k^2 p^{3/2}) \ (n^2/bB^2) \quad (31)$$

where m_e and m_i are the masses of the electrons and of the mean con-ducting ions respectively. The data necessary to evaluate (31) at the base of the chromosphere are not reliable except perhaps as to order of magnitude. At the base of the chromosphere we adopt as representative, $n = 10^{11}$ ions/cc, $B = 10^{-2}$ gauss, $m_i = 5 \times 10^{-24}$ gm, $u = 5 \times 10^4$ cm/sec, $b = 0.06$ cm, sec, and find that equilibrium is not attained until T_e approxi-mates 26,000°. The exact value calculated has little significance since the selected value of b may be too large. However, the form of the expressions seems significant and shows that equilibrium cannot be achieved unless the effective temperature is high. The calculated value of 26,000° does not appear excessive.

The foregoing calculations suggest that the outstanding features of chromospheric excitation, particularly those of neutral and ionized helium ($\lambda 4686$, total ionization and excitation potential 74 volts) and hydrogen are due to the presence of high-speed electrons and electric fields in the chromosphere. Indeed, using the above effective electron-temperature

[9] R. Gunn, Phys. Rev., **36**, 1251-1256 (1930).

and the usual Saha expression, it is found that the ratio of the number of helium ions in the state to emit λ4686 to the number of one quantum neutral helium atoms is 10^{-4}. Thus, even though the abundance of helium in the Sun may not be particularly great, yet according to the present investigations, the appearance of a strong line at λ4686 is to be expected.

If the present estimates of the constitution and pressure-distribution in the Sun's atmosphere are correct, there is no reason to believe that the true thermodynamic temperature even approaches the effective electron-temperature just calculated, except possibly in the corona. It does appear, however, that the excessive energy of a fraction of the chromospheric particles may be sufficiently great to modify in an important manner the theoretical pressure-gradients. Indeed, it appears quite possible that the chromosphere may actually be in gravitational equilibrium and supported by gaseous pressure. More data are required before a decision can be made.

The present theoretical investigation supports our earlier conclusions in every important detail. The eastward electromagnetic wind-velocity calculated from pure theory agrees in form and magnitude with that observed. Hence the distribution and magnitude of the solar electric field must closely approximate that calculated from the data of the anomalous rotation. The theory further suggests why the properties of the reversing layer are much different from those of the chromosphere and why excessive excitation-effects are present only in the latter region. The suggestion is made that the zone dividing the reversing layer and chromosphere might conveniently be defined as the zone where $q_t = q_s$.

The difficulty of assigning precise values to some of the quantities in the developed relations, particularly the ionic pressures, does not permit one to draw definite conclusions. However, the rough agreements and particularly the form of the relations, together seem to establish a strong presumption for the existence of solar electric fields of the calculated magnitude and for high excitation in the chromosphere due to the associated high-speed electrons.

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THE ASSOCIATION BETWEEN RELATIVE HUMIDITY AND THE RATIO OF THE NUMBER OF LARGE IONS TO THE TOTAL NUMBER OF NUCLEI

By H. L. Wright

Abstract—Theoretical reasons are advanced which support the observation, noted by O. W. Torreson, that the diurnal variation of the ratio N_1/N closely resembles the diurnal variation of relative humidity. A formula is obtained which relates the ratio N_1/N to the radius of nuclei.

(1) Introduction

In a recent paper Torreson[1] has called attention to the similarity between the curve showing the diurnal variation of N_1/N, (where N_1 denotes the number of positively charged nuclei and N denotes the total number of nuclei) and the curve showing the diurnal variation of relative humidity. Torreson points out that this similarity may be interpreted in two ways: (1) Observations with the nucleus-counter may be open to suspicion owing to the possibility that when humidity is high nuclei become laden with moisture and are caught in the passages of the counter, with the result that the observed number of droplets is too low; or (2) the phenomenon is real and has to be taken into account in theoretical studies of the equilibrium of ionization.

It is important that any suspicion attaching to the nucleus-counter be removed as soon as possible since observations with this instrument are fundamental in the study of atmospheric ionization. The purpose of the present note is to show that the second interpretation may be placed on Torreson's result inasmuch as an association between the ratio N_1/N and the relative humidity is to be expected and may be accounted for on theoretical grounds.

(2) The Significance of the ratio N_1/N

The notation which will be used is as follows:

N_1 = number of large positive ions per cc (that is, nuclei with $+$ charges)

N_2 = number of large negative ions per cc (that is, nuclei with $-$ charges)

N_0 = number of uncharged nuclei

$N = N_0 + N_1 + N_2$ = total number of condensation-nuclei per cc

n_1 = number of small positive ions per cc

n_2 = number of small negative ions per cc

w_1 = mobility of a small positive ion

w_2 = mobility of a small negative ion

q = rate of production of pairs of small ions per cc per sec

e = electronic charge per ion

The combination-coefficient η_{10} is defined by the statement that the frequency of combinations of small positive ions with uncharged nuclei is $\eta_{10} n_1 N_0$ per cc per sec, and similar definitions hold for η_{20}, η_{12}, η_{21}.

[1] O. W. Torreson, Terr. Mag., **39**, 65-68 (1934).

The equilibrium-equations between small ions and nuclei, when nuclei are plentiful, are

$$\eta_{10}n_1N_0 + \eta_{12}n_1N_2 = q = \eta_{20}n_2N_0 + \eta_{21}n_2N_1 \tag{1}$$

The equilibrium-equations for large ions are

$$\eta_{10}n_1N_0 - \eta_{21}n_2N_1 = 0 = \eta_{20}n_2N_0 - \eta_{21}n_1N_2 \tag{2}$$

According to the theory recently put forward by Whipple[2] the combination-coefficients are related by the formulæ

$$\eta_{12} - \eta_{10} = 4\pi e w_1 \text{ and } \eta_{21} - \eta_{20} = 4\pi e w_2 \tag{3}$$

Assuming that there is no volume charge we may write

$$N_1 = N_2 \tag{4}$$

and it is further assumed that in unit-volume and in unit-time the frequency of combinations between small ions and uncharged nuclei is the same for positive as for negative small ions, that is

$$\eta_{10}n_1N_0 = \eta_{20}n_2N_0 \tag{5}$$

Assumptions (4) and (5) take the place of the usual assumptions of complete symmetry, namely: $N_1 = N_2$, $n_1 = n_2$, $w_1 = w_2$, $\eta_{10} = \eta_{20}$, and $\eta_{12} = \eta_{21}$. The assumption of complete symmetry is not necessary and, moreover, it is hardly borne out by the facts since it is a matter of common observation that generally n_1 is slightly greater than n_2 and w_2 is slightly greater than w_1. According to the present assumptions we have from (5) and (2)

$$\eta_{21}n_2N_1 = \eta_{10}n_1N_0 = \eta_{20}n_2N_0 = \eta_{12}n_1N_2 \tag{6}$$

whence using (4) and (3)

$$n_1/n_2 = \eta_{20}/\eta_{10} = \eta_{21}/\eta_{12} = (\eta_{20} + 4\pi e w_2)/(\eta_{10} + 4\pi e w_1) = w_2/w_1 \tag{7}$$

This result is in agreement with observations generally of the concentration of positive and negative small ions and of their mobility.

It follows from (6) that

$$N_0/\eta_{12} = N_1/\eta_{10} = N_2/\eta_{10} = N/(\eta_{12} + 2\eta_{10})$$

whence from (3)
$$N_1/N = \eta_{10}/(\eta_{12} + 2\eta_{10}) = \eta_{10}/(3\eta_{10} + 4\pi e w_1)$$

It is reasonable to suppose and indeed it is implied in Whipple's paper that the frequency of collisions between small ions and uncharged nuclei is proportional to the surface-area of the nuclei and the radial component of the velocity of small ions. If we denote the effective

F. J. W. Whipple, Proc. Phys. Soc., **45**, 367–380 (1933).

radius of a nucleus by R and the radial component of the velocity of small ions due to Brownian movement by v and if every collision is succeeded by recombination we may write $\eta_{10} = 4\pi R^2 v$ and hence

$$N_1/N = 1/(3 + ew_1/vR^2) \qquad (8)$$

The values usually taken for e and w_1 are 4.77×10^{-10} e. s. u. and 330 e. s. u., respectively. An approximate value may be assigned to v. It is generally supposed that small ions consist of a cluster of some ten or a dozen molecules of water-vapour associated with a charged atom of oxygen or nitrogen. If v_1, v_2, v_3 are the components of velocity of a cluster of molecules each of mass m, the kinetic energy of the cluster is $nm (v_1^2 + v_2^2 + v_3^2)/2$ and by the kinetic theory of gases this equals $3R'T/2N'$ where R' is the gas constant $= 8.32 \times 10^7$ erg gm mol, T is the temperature = say 290° absolute in the present case, and N' is Avogadro's number. The mass of a molecule of water-vapour is equal to $18/N'$. Taking n, the number of molecules in a small ion cluster, to be 12, and writing $v_1 = v_2 = v_3 = v$, we find that $v^2 = R'T/12 \times 18$ whence $v = 10^4$ cm/sec. Substituting this value of v and the values of e and w_1 stated above in (8) we have

$$N_1/N = 1/(3 + 15.8 \times 10^{-12}/R^2) \qquad (9)$$

(3) Conclusion

The variation between N_1/N and R given by formula (9) is as shown in Figure 1. It may be seen from the diagram that when the radius of the nuclei is large the ratio N_1/N is high, and as it may be supposed that
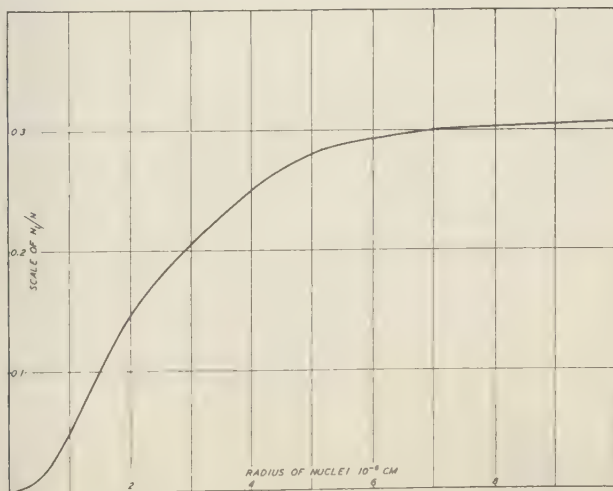
FIG. 1—THEORETICAL RELATION BETWEEN THE RADIUS OF NUCLEI AND THE RATIO OF THE NUMBER OF CHARGED IONS OF ONE SIGN TO THE TOTAL NUMBER OF NUCLEI

increase in relative humidity leads to increase in the size of nuclei the association between relative humidity and the ratio N_1/N is explained, at least qualitatively.

Quantitative examination of Torreson's results is however less satisfactory. According to Torreson's graph the values of N_1/N range from 0.12 in the afternoon to 0.49 at about 5^h, whereas according to theory values of N_1/N above one-third are impossible. That Torreson finds values greater than this figure may be because the data on which his values are based were not strictly comparable, the diurnal variation of N_1 being obtained from records on sixteen days in March 1932 while the diurnal variation of N was derived from observations on four days late in March in three different years, 1927-28-30. If the values greater than one-third found by Torreson are reliable it is implied that the present theoretical development is invalid or at least requires modification. The presence of multiply-charged nuclei for example would be sufficient to invalidate the equations given above.

Torreson's minimum value of 0.12 for the ratio N_1/N corresponds to a value for the effective radius of the nuclei equal to about 2×10^{-6} cm. As the value usually accepted[3] for the average radius of nuclei is about 4.5×10^{-6} cm this seems a reasonable value for the mean diurnal minimum.

The interpretation of the ratio N_1/N indicated by theory reveals a very simple method of deducing values of the effective radius of nuclei, a quantity which hitherto it has not been possible to study closely. The observational results noted by Torreson are in general agreement with such an interpretation though discrepancy in detail remains to be settled.

At present it may be said that there is reason to suppose that humidity indirectly affects the equilibrium of ionization by leading to changes in the size of nuclei and that a diurnal variation in the ratio N_1/N is to be expected which follows more or less closely the diurnal variation in relative humidity.

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A STUDY OF ATMOSPHERIC DUST USING A CONTINUOUS RECORDING JET-COUNTER

By Russell A. Nielsen

Abstract—A new device for continuously recording the dust-content of the air has been used to obtain records of atmospheric dust at Stanford University, California. Continuous dust-records from January 13 to March 17, 1934, have been taken and the variations in the dust-content of the air correlated with other atmospheric phenomena recorded at this station. In particular, the space-charge tended to vary inversely as the dust-content, while the potential gradient seemed to be unaffected by changes in the amount of dust.

Introduction

This paper presents the results of a two-month series of records of dust-variation in the atmosphere, as continuously recorded by a modified type of Dr. Owens' jet-recorder, which was built specially for this experiment.

Three types of apparatus have been used in connection with studies on particles in the air: (*a*) The Aitken pocket "dust"-counter; (*b*) the Owens' automatic filter; and (*c*) the Owens' jet dust-counter. In the Aitken instrument [1, for references see end of article] a known volume of air is admitted into a chamber containing water. When the air inside this chamber is expanded, the water-vapor condenses upon the nuclei, forming small water-drops which fall under the influence of gravity. Some of these drops are caught upon a polished surface, and the number per unit-area is counted with the help of a microscope. In the automatic filter [2] a known volume of air is drawn through a white filter-paper. The amount of matter collected is then estimated by comparing the tint of the stain on the filter-paper with a scale consisting of a calibrated series of tints. The weight of the matter suspended in the known volume of air is then obtained by multiplying the tint by a corresponding factor. In the jet-counter [3] a known volume of moistened air is drawn through a slit by a hand pump. The air passing through the slit impinges on a glass slide, to which the moistened particles adhere. This slide can then be removed and the particles counted and examined under a microscope.

The Aitken instrument counts nuclei of condensation; the two Owens' instruments count the larger, more fragmentary suspensoids [4]. The record of the automatic filter depends upon the discoloration of filter-paper. Where smoke is the predominant contamination in the air, the instrument serves well; but in a district, such as Stanford University and vicinity where the contamination is comparatively small, the jet-counter proves more useful.

The jet-counter as previously used was manually operated, observations being taken daily. At Kew Observatory, England, daily records with the jet-counter have been taken at the 15th hour. Kimball and Hand have taken similar records in Washington, D. C. These observations with the jet-counter have not been made frequently enough to truly represent either short- or long-period dust-variations. This paper deals primarily with the effect of short-period variations of the dust in the air upon the space-charge and the potential gradient of the atmosphere. In order not only to record variations of short duration and sudden changes of magnitude, but also to obtain records during both day and night, it was

necessary to construct a continuous recording apparatus. The design and construction of the apparatus are the subject of the first part of this paper while the second part deals with the results of continuous observations with the instrument from January 18 to March 17, 1934. An Owens' jet-counter was not available at this University, so the first apparatus built, though similar to that of Dr. Owens, was of a very flexible nature. The width, length, and depth of jet, as well as the pressure-difference across the jet, were adjustable over wide limits. These were varied until a usable record was obtained after a continuous flow of air for 20 minutes. Three records per hour giving 72 records per day could be deposited on one microscope-slide, so the apparatus was designed to handle one day's records automatically. The records were removed daily and could be examined microscopically to determine changes in the type of dust. Manual counting of such a number of records was impossible, so in order to record automatically the quantity of dust deposited on the glass slide, a photronic cell, placed below the dust-record, was connected to a galvanometer, whose deflection was recorded continuously on photographic paper. A beam of light, focused on the jet of the apparatus, passed through the dust-record which was continuously forming on the microscope-slide, and then fell upon the photronic cell. A continuous photographic record of the dust-variation was therefore obtained. The airflow was maintained constant by a motor-driven pump. Records from the apparatus would repeat under identical dust-conditions, and variations in the atmospheric temperature and humidity, under the conditions used, had no observable effect on the deposition of the dust.

APPARATUS

The body of the apparatus was a rectangular brass box, 3.25 by 6.25 by 8.5 inches. The sides and bottom were of 0.1-inch sheet brass. The ends, one side, and the bottom were soldered together as shown in Figure 1. A rectangle 0.87 by 4.12 inches was cut from one of the ends, and a
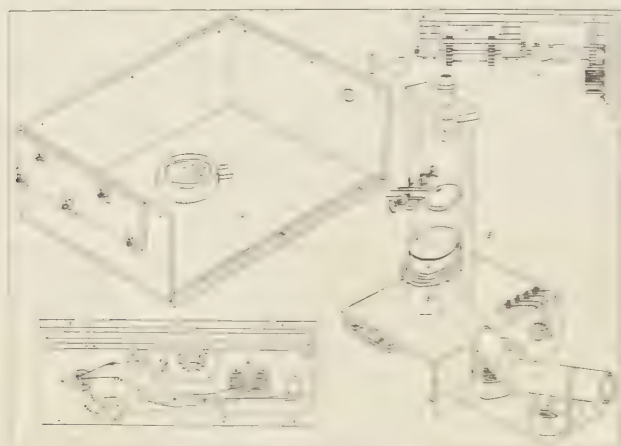
FIG. 1—DIAGRAMMATIC SKETCHES MODIFIED TYPE OWENS JET-RECORDER—A, RECTANGULAR BASE; B, EXTERNAL PART; C, END ELEVATION OF INTERIOR; D, SIDE ELEVATION OF INTERIOR

plate 1.5 by 5.5 inches, with a sheet of 0.2-inch rubber cemented to one side of it, acted as a door for this opening. The record on the microscope-slide was removed through this door. Five wing-nuts held the door in place and kept it air-tight. Opposite this door is the tube through which the air was removed from the apparatus. The photronic cell was fastened to the bottom of the apparatus.

A piece of quarter-inch brass was used for the top of the box. The second side was soldered to the top and all the mechanism was fastened to this part. The apparatus was therefore in two sections (Fig. 1); the top with its connected equipment was screwed to the bottom section and all joints were made air-tight by covering them with bees-wax.

The exterior part of the apparatus consisted of a frame for holding the light and lens-system, and the moistening chamber for the incoming air. The lens-system focused an image of the filament of the light upon the jet. The part marked A on the Figure is a cap which has a glass top. The joint between A and B is made air-tight by covering it with lanolin. The tube C is lined with blotting paper which is kept moist by cotton which dips into the water in containers D and E. The cotton is in rubber tubes which end beneath the water, so no air can enter except through the end of tube C. On the side soldered to the top, four wires are sealed in through glass. Two wires carry current from the photronic cell; the other two carry the current which actuates a magnet. F is the track on which the carrier of the microscope-slide moves. The carrier for the microscope-slide is shown in Figure 2. Lying over the center of the
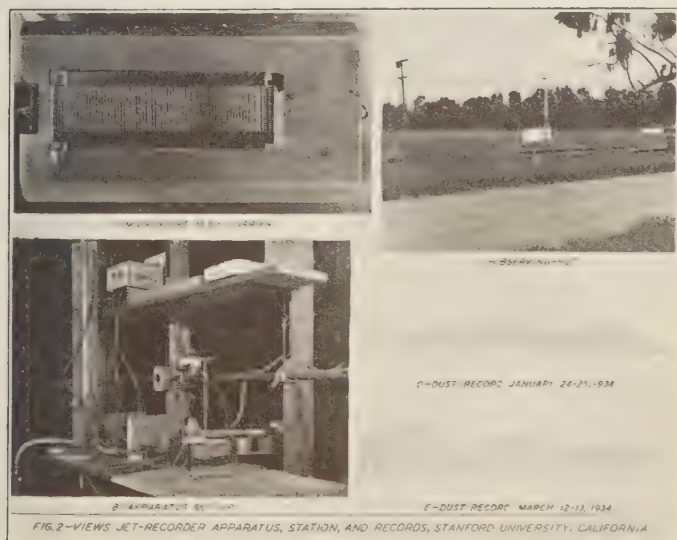
FIG. 2—VIEWS JET-RECORDER APPARATUS, STATION, AND RECORDS, STANFORD UNIVERSITY, CALIFORNIA.

carrier is a microscope-slide containing one day's dust-record. The central part of the carrier was cut away in order to allow the light focused on the jet to strike the photronic cell, which lies below the carrier in the

assembled apparatus. The under side of the slide contains two racks which engage with the gears G. The magnets M actuate the ratchet-arm which turns the ratchet-wheel, the axle of which is connected by rubber tubing to the axle on which the gears are fastened. Once every 20 minutes a current from a timer actuates the magnet. The ratchet-arm moves the ratchet-wheel, and the gears then force the carrier of the microscope-slide 0.04 inch forward. The door shown in Figure 1 is just large enough to allow the slide-carrier to be removed through it. A rectangle 1 by 1.5 inches is cut in the bottom of track F to allow the gears to engage the rack on the bottom of the carrier, and the light to fall upon the photronic cell.

The jet H was made of two pieces of brass beveled to 45°. One piece was soldered to the under side of the top, the other was screwed in place. The ends of the jet were also made at a 45°-bevel by filling them with bees-wax. A coat of shellac over the bees-wax provided a smooth surface for the air to flow across.

The timer for actuating the magnet consisted of a fiber wheel, rotated once per hour by a telechron motor. Three evenly spaced copper strips were inserted on the periphery of the wheel and were connected to the wheel's axle. A wire dragged on the periphery of the timer-wheel and made contact to one of these strips every twenty minutes, and the current operated a relay which was connected to the magnet.

The T-tube was connected to a water manometer and to a buffer-tank which was kept partly evacuated by a belt-driven pump.

Connection was made from the photronic cell to the galvanometer by means of a tube-base N which connects with the binding-posts outside of the apparatus through the glass seal Q. The galvanometer-terminals were connected to these binding-posts. A small light was focused so that the beam after reflecting from the mirror of the galvanometer came to a focus on the surface of a revolving drum, 6 inches wide and 20 inches in circumference. The drum, whose surface was covered with photographic paper, was enclosed in a box which had a narrow slit parallel to the drum's axis. The width of the slit determined the width of the line on the photographic record. The maximum deflection for the galvanometer (no dust on the microscope-slide, and therefore maximum light on the photronic cell) was less than 6 inches, so the movement of the galvanometer was always recorded by the spot of light moving across the surface of the drum. The drum was driven by a telechron motor which rotated it once per day. In this way one microscope-slide record and one corresponding photographic record were obtained per day. Any variation of the amount of dust being deposited would show on the photographic record at the exact minute at which the change occurred; its magnitude also, though the variation lasted only a minute, would be recorded on the photographic paper.

The intake-tube projected through a hole in the wall of the observation hut. The small space between the hole and the tube was made air-tight, so that no air from inside the hut would be taken into the apparatus. The blotters over which the air flowed were kept moist continually. The moistening chamber consisted of two tubes (C, Fig. 1). One was 0.87 inch in diameter and 6.7 inches long; the other was 1 inch in diameter and 5 inches long. The latter was the intake-tube and was fitted to the other by an air-tight joint. The air drawn through these tubes passed through the jet and then through the buffer-tank to the

exhausting pump. If large particles lodged across the jet, they could be dislodged by removing the cover *A* and pushing a 0.004-inch thickness gauge through the jet. A difference of pressure of 6 inches of water was maintained by the pump. Such a low pressure-difference caused no fogging of the air as it passed through the jet. The deflection of the galvanometer did not decrease when the air-flow was turned off; this showed that the photographic record was a record of dust alone, and not a record of dust and fog. The buffer-tank (15-gallon capacity) smoothed out the effect of the stroke of the pump so that the air-flow through the apparatus was constant. The flow was 0.2 cubic foot per minute and the average velocity of the air through the jet was about 225 feet per second.

The intensity of the light focused on the jet and incident on the dust-line was maintained constant by connecting the filament of the lamp to a storage-battery whose potential was kept constant by a trickle-charger.

The dust that adhered to the microscope-slide was of two kinds: (*a*) Carbon and opaque particles; (*b*) hygroscopic and translucent particles. The carbon particles absorb and scatter light. Those of the translucent variety absorb little, but transmit and scatter most of that which is incident upon them. In order to record photographically the amount of matter on the microscope-slide, it was necessary to place a mask over the photronic cell. This mask had a small opening which was the size of the light-beam when unobstructed by dust. The cell received all direct light; the mask intercepted almost all of the scattered light. This was found to be a very satisfactory way of equalizing the effect of the different kinds of dust.

Figure 2 shows the apparatus as set up for this experiment. At the right of the picture is shown the moistening tubes projecting through a hole in the wall of the observation-hut. The containers for the water— required to keep the blotting paper moist—are fastened to the tube. At the left of the apparatus proper is the box containing the timer for actuating the magnet. To the left of this is the manometer. The object in the lower left-hand corner is the top of the buffer tank.

Experimental Results

The apparatus was installed in an observation-hut (Fig. 2) which was built purposely for experimental work in atmospheric electricity. The records of space-charge, potential gradient, and dust were all taken at this hut. The intakes for space-charge and for the dust were each one meter above the ground. The filter-method [5] was used to measure the space-charge. A radioactive collector connected to an electrometer registered the potential gradient two meters above ground. The observation-hut is about 50 yards to the east of a small experimental greenhouse, while on the other side, about 100 yards away, is the Carnegie Laboratory of Plant Biology. The hut is about 75 yards from the dirt-road shown in the foreground of the picture. The surrounding country is comparatively open. A half-mile to the east are the buildings of Stanford University; a mile to the northeast is the main-line railroad between San Francisco and Los Angeles. On the other side of the railway is Palo Alto, a residence town of about 15,000 population. To the south lies open country which rises to mountains. The ocean is about 15 miles air-line across the mountains.

Two kinds of records were taken by the apparatus: the first was the actual dust as deposited on the microscope-slide, one ribbon of dust each 20 minutes (Fig. 2); the other was the photographic record. Both of these records were changed each morning at 8^h. The height of each line on the photographic records is a measure of the amount of dust deposited in a 20-minute period. The record of March 12-13 (lower one, of Fig. 2) was of interest in that it showed a rare occurrence, namely, a period of about ten hours during which time the amount of dust in the air remained constant. The extra height of the third line from the end was due to a local disturbance at 7^h—undoubtedly because of the dust raised by a passing car and carried past the hut by the wind. The record of January 24-25 (upper one, Fig. 2) gives an idea of the variation of the amount of dust during a day. After a sudden increase of the dust-content of the air (as shown near the center of the record), the return to previous values usually takes an hour or more. The magnitude and duration of the "excess" dust depend on the source of the dust, and the direction and velocity of the wind. The height of the lines on the photographic records is not a linear measure of the amount of dust on the record; it is a linear measure of the opacity of the dust deposited on the slide. The opacity is an exponential function of the amount of dust, which function must be slightly modified due to the piling up of the dust when large quantities are deposited on the slide. An experimental calibration-curve was made and all values measured from the photographic records were corrected to linear values before being used in computing points for the graphs.

On all the curves the scales of dust, potential gradient, and space-charge are arbitrary. However, after being selected, the same scale is used for all the curves. The zero-point of the curves, except in Figure 4, is in each case the bottom boundary of the graph. In Figure 4 the zero-points of the two curves have been separated, since the general characteristics of the curves are obscured if they cross too much.

To determine the variation characteristics of different conditions, the days of the experiment were divided into groups, namely, clear days, cloudy days, hazy and foggy days, and days of fires. The last division comprised five days (March 6-10) when earth was being sterilized at the Carnegie Laboratory in an outdoor oven which was heated by a wood fire. About 8^h when the fire was started there was much smoke, but in a few minutes the visible smoking from the chimney ceased. More wood placed on the fire about once per hour caused a little smoking at those times. This sterilization of earth was carried on for five days and therefore a separate curve of the dust and space-charge was made to determine the effect of such a nearby fire. The days on which the Carnegie Laboratory had these fires will hereafter be referred to as "days of fires."

Figure 3 shows the mean diurnal variation of the dust and of space-charge for the 50 days on which records were obtained. It should be noted that on this curve the space-charge remains low throughout the day. It first decreases as the dust rises toward its first maximum, and increases as the dust decreases from its second maximum. The minimum of dust at 15^h is not accompanied by an increase in space-charge. The dust-variation on clear days is essentially the same as the mean of all the days. The space-charge, however, rises in the early morning until the local air-
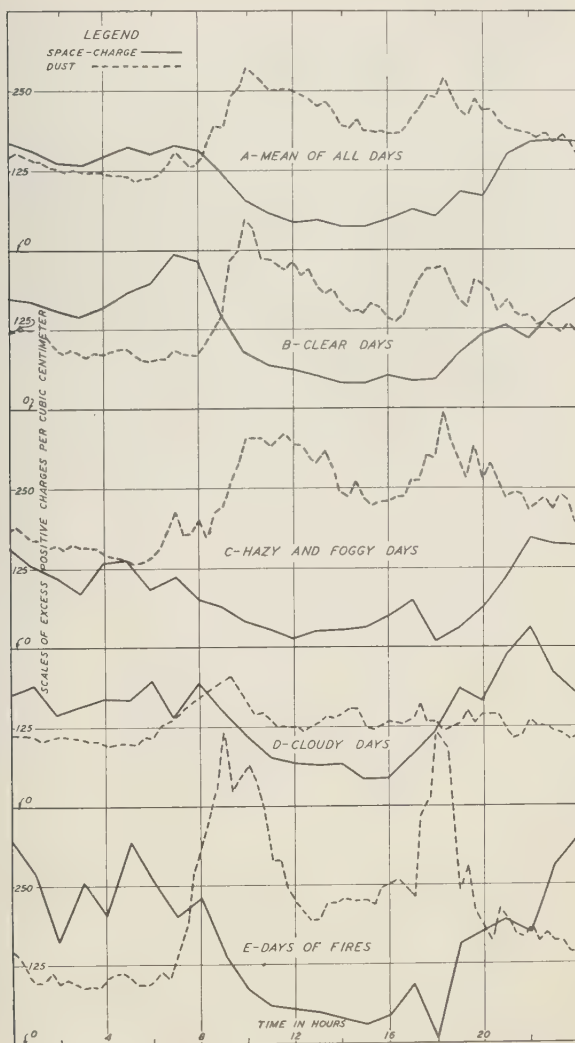
FIG. 3—DIURNAL COURSES OF DUST AND OF SPACE-CHARGE,
STANFORD UNIVERSITY, CALIFORNIA, JANUARY TO MARCH, 1934

. disturbance causes mixing of the air, and a decrease of space-charge and
increase of dust result [6]. The dust on hazy and foggy days is consider-
ably above the mean, though the shape of the curve remains the same.
The evening maximum, however, gains predominance and is as great as
the morning maximum. The peculiarity of the space-charge curve,
namely, the minimum at the 18th hour, will be discussed later. On

cloudy days the dust has a minimum of variation. The morning maxi-
mum is extremely small; the evening maximum has disappeared. The
curve for days of fires is of special interest in regard to the great heights
of both morning and evening maxima and to the near average value of
the afternoon minimum. The irregularity of the space-charge in the
early morning is undoubtedly due to two things: First, the curve repre-
sents only a mean of five days; second, some of the days had an early
morning fog and some were hazy or clear. Such a mixture in five days
cannot be expected to give a smooth curve. It should be noted that a
minimum of space-charge at the 18th hour corresponds to the second
maximum of the dust.

Figure 4 illustrates well the trends of the preceding curves. On this
curve the points represent the average values of the space-charge and dust
for the entire day. The curves on this plot are displaced so that their
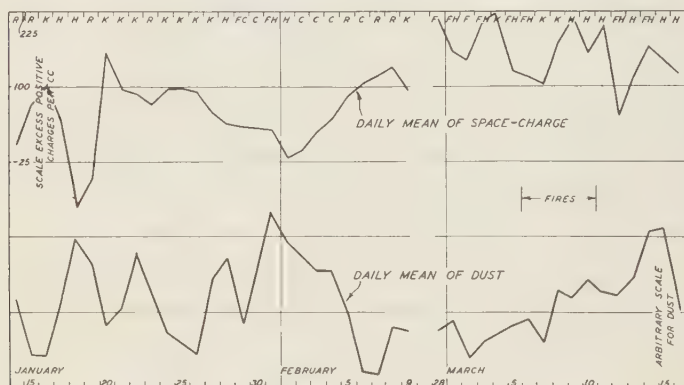
FIG. 4—DAILY MEANS OF DUST AND OF SPACE-CHARGE, STANFORD UNIVERSITY,
CALIFORNIA, JANUARY TO MARCH, 1934
(C=CLOUDY; F=FOGGY; H=HAZY; FH=MORNING FOG BUT HAZY DAY; K=CLEAR; R=RAIN SOMETIME DURING DAY)

zero-points do not coincide. The meaning of the letters below the curve
is as follows: R, rain sometime during the day; K, clear day; C, cloudy
day; F, foggy day; H, hazy day; and FH, morning fog but hazy day.
Figure 4 shows that dust-averages vary inversely as the averages of space-
charge during January 14 to 20; from January 21 to 30, the inverse
relationship does not hold; from January 31 to February 9, the inverse
relationship again predominates; from February 28 to March 16, only the
general tendencies of the two curves are inverse. The shorter variations
in the last-mentioned group do not show the inverse relationship, though
as an average over that 17-day period, the space-charge slowly decreases
as the dust increases. From February 10 to 28 a series of breakdowns
interrupted the recording so much that it was thought best to omit
these days.

On days of fires, the fact that the height of the morning maximum
was above the average was due probably to two causes: (1) Some of
the days were hazy days which are usually characterized by high-dust-
values; (2) the local fire which started at about 8^h. The fire was out at

$17^h\ 30^m$ or 18^h. One day being Saturday, the fire was out at 13^h, but even in this case the record showed a maximum at 18^h slightly exceeding the morning maximum for that day. The second maximum could not, therefore, have been due to the fire but must have had some other cause. The appearance of an evening minimum of space-charge at the same time as the second maximum of the dust, was characteristic of foggy and hazy days (Fig. 3). On clear days the effect was noticeable, though not prominent. On cloudy days the space-charge rose from its mid-day minimum earlier than usual; this might be accounted for by saying that the factor causing the evening space-charge minimum was absent, or that other electrical conditions when clouds were present masked the effect.

According to the theory of J. G. Brown, the "turbulence, which mixes the air near the surface with the higher air, can account quite well for the diurnal variation of space-charge near the surface" [6]. Since the dust tends to vary inversely as the positive space-charge, it follows that if the dust is a factor in the decrease of space-charge, then the morning decrease of space-charge is aided by the increase of dust, while the evening increase of space-charge is delayed or interfered with by the second dust-maximum. To account for a decrease of the positive space-charge with increase of dust, we must postulate that the dust itself has a negative charge. J. G. Brown [5] finds that the space-charge becomes negative when the dust which is raised by sweeping a sidewalk, is carried past the recorder by the wind. He also finds that if the wind is strong enough to fill the air with dust blown up from the roads, etc., the space-charge becomes very negative and the potential gradient decreases also. Observations of space-charge on days of fires shows that the dust given off from the fires had only a very small effect upon the space-charge. On certain days an increase of dust is accompanied by a decrease of space-charge. At other times, even during the same day, the space-charge seems independent of the dust-variation. This effect is probably due to dust coming from different sources. All the curves show a strong inverse correlation between the space-charge and the dust in the air. It seems therefore that the dust carries negative charge. Microscopic examination fails to reveal any distinguishing characteristics between the dust that affects the space-charge and that which does not.

It is of interest to note that the large-ion curve of Washington, D. C. [7] follows a curve somewhat similar to the space-charge curve for Stanford; also the condensation-nuclei curve for Washington, D. C. [8] is in agreement with the dust-curve at Stanford; however the space-charge curve for Washington agrees better with the Washington condensation-nuclei curve than with the Stanford space-charge curve. To get farther toward the solution of the problem requires simultaneous measurements of other atmospheric-electric elements besides those of dust, space-charge, and potential gradient. Without these I think it unwise to speculate too much upon the interdependence of the factors, and the part the dust plays in the problem.

Microscopic examination of actual dust-records shows that there are sometimes present on hazy days small needle-like or rhomboid crystals, and small, oval, translucent particles. These are absent on clear days, so it seems that the haze in part at least is of sea-origin, for the crystals look like salt-crystals, and it is this type of particles that Dr. Owens found in sea-haze. Crystals are also prominent at the time of rain.

4

Sometimes their presence precedes the coming of a rain, while at other times they come at just about the start of the rain. Figure 6 shows microphotographs of a line of dust deposited on the microscope-slide. The first is under the average in density, and such a condition is usually typical of the period at the start of a shower. The next is well over the average in density. The black aggregates are formed by groups of small particles like those in the preceding photograph. In observing other records it could be seen that the small particles were tending to stick to each other and to form little chains. The aggregates seem to be great quantities of such chains all adhering together. The last photograph shows the crystals after a rain. The black particles have been washed out by the rain and the crystals are all that remain. These three dust-records were taken within a few hours of each other on the day of a rain.

From February 25 until after the end of the experiment on March 17 there was no rain; almost all of these days were of the hazy type. The dust-records began to show a sort of yellow color due to the presence of translucent yellow colored particles. On the days of fires, which followed the coming of the yellow particles, the starting of the fire made the record quite black, but in about an hour the yellow coloring regained its prominence. The record at the time of starting the fire contained, besides particles of black smoke, many small yellow colored droplets. These evaporated extremely slowly, leaving a yellow crystalline substance on the slide. The droplets were probably pitch which volatilized when the wood burned and condensed on particles with which it came in contact.

The potential-gradient curve for Stanford is characterized by a strong primary maximum at 9ʰ and a very weak maximum at 22ʰ. The similarity between the double maxima potential-gradient curve and the double maxima pollution-curve for Kew Observatory is most striking [9]. In contrast to this, Stanford has the single maximum-type curve for the potential-gradient variation but a double maximum for the dust-variation. Both maxima of the dust-variation curve are narrower than those of England. The cause of our double dust-maximum is probably the same as that of England—man-made. The railroad is a source of a considerable quantity of particles. The trains start at about 5ʰ 30ᵐ, and
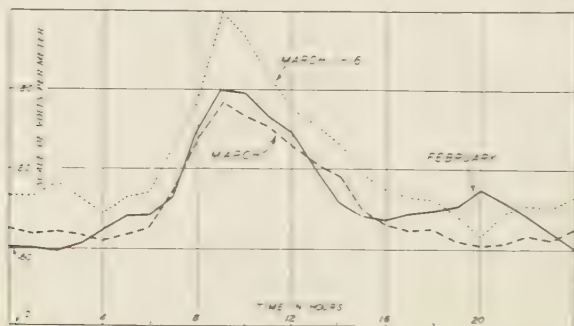

FIG. 5—DIURNAL COURSE ATMOSPHERIC POTENTIAL–GRADIENT, STANFORD UNIVERSITY, CALIFORNIA, FEBRUARY AND MARCH, 1934

58 passenger trains pass per day; 14 of them pass between 5^h 30^m and 8^h 30^m. This alone would greatly increase the number of particles suspended in the quiet morning air. The wind, rising soon thereafter and blowing throughout the day, probably mixes the dust-free air from above with the lower air and thus produces a dust-minimum during the day. When the wind quiets down as it usualy does about 17^h or 18^h, the particles are not removed as fast as they are being put into the air, and the second maximum results.

The potential-gradient curve for the first 16 days of March (almost all the sixteen days being of the hazy type) is higher than that of either the preceding month or of the entire month of March (Fig. 5). This is in accord with the results of other observers, who have found the potential gradient higher for days of fog or haze [10].
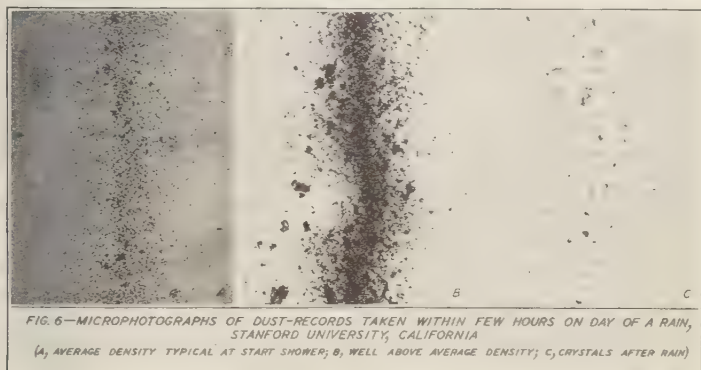

FIG. 6—MICROPHOTOGRAPHS OF DUST-RECORDS TAKEN WITHIN FEW HOURS ON DAY OF A RAIN, STANFORD UNIVERSITY, CALIFORNIA
(A, AVERAGE DENSITY TYPICAL AT START SHOWER; B, WELL ABOVE AVERAGE DENSITY; C, CRYSTALS AFTER RAIN)

Figure 5 gives three potential-gradient curves, none of which exhibits any definite signs of having been influenced by the dust-maximum at 18^h. The curve of hazy and foggy days, and the curve for days of fires, together comprise almost all of the first 16 days of March and even these very high values of the evening dust-maximum do not show their effect on the corresponding potential-gradient curve. This lends support to one of the results of Wright [11], who concludes, after a careful consideration of the effect of atmospheric suspensoids on the Earth's electric field, that, "No direct influence of the gross particles on the potential gradient is apparent."

The author takes this opportunity of thanking Professor J. G. Brown for guidance in this investigation. It was made possible through his interest and cooperation.

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SUMMARY OF SOME AURORAL HEIGHT-MEASUREMENTS AND OBSERVATIONS AT CHESTERFIELD, CANADA*

By B. W. Currie

The Aurora-Borealis investigations of the Canadian International Polar-Year party located at Chesterfield Inlet, (63° 20′ north, 90° 42′ west), comprised single-station visual observations, single-station photographs of the brighter displays, and double-station photographs for height-measurements. To date height-measurements have been made on 200 of the parallactic photographs, and a study has been made of the visual observations on nights without cloud.

The secondary auroral station was located south of Chesterfield on the coast of Hudson Bay. It was established during September, 1932, when it was possible to travel along the coast by boat. A sod shelter, Figure 1, was built, and a supply of food and kerosene left there for future use. The position of this station relative to the Chesterfield station was determined the following spring by triangulation and stadia-rod surveys over the Bay ice. The values obtained were: Length of base-line, 33.14 km; azimuth from north, +173° 39′.

Only one-way communication by radio from Chesterfield to the secondary station was possible, the use of the Canadian Government Radio Station and its personnel having been placed at the disposal of the party. A telephone-line was run from the Chesterfield camera-station to the Radio Station. Camera-direction and other pertinent data were telephoned to a member of the party at the Radio Station. He immediately broadcasted it to be picked up by the man at the camera at the secondary station, who was equipped with a portable radio receiving-set. After a short pause to allow the second man to adjust his camera, "On" was broadcasted over the air, but was also heard by the first camera man over the telephone-line; thus the exposures on the two cameras were made practically simultaneously. Similarly, the order to stop the exposures came from the first camera man, and was done as soon as it was broadcasted. Time and duration of exposure (read from a chronometer), form, intensity, and other information concerning the auroræ were recorded by the individual at the Radio Station. This method was found to be very successful except for rapidly moving or changing auroræ. Figure 2 shows the camera-station at Chesterfield, while Figure 3 shows a view of the secondary station in winter.

The cameras were of the usual Krogness type, which allows six pictures to be taken on the same plate. The objectives of the cameras were of the Astro R. K. type, F:1.25, focal length 5 cm. Eclipse Ortho Soft plates were used.

Five trips were made to the secondary station by the writer during the winter; three of these were successful. Parallactic photographs were obtained during the periods January 22-29, February 26-28, and March 21-27. The dates are inclusive and are according to Greenwich time. One thousand photographs were taken with apparently about two-thirds useful for height-measurements.

FIGS. 1-4—INTERNATIONAL POLAR YEAR STATION, CHESTERFIELD, CANADA, 1932-33

The methods of measuring the parallactic angles and determining the auroral heights are those developed by Störmer[1], Vegard and Krogness[2], and Harang and Tønsberg[3]. "Nets" were prepared for each 4°-interval from the celestial pole to the equator. The nets in conjunction with the "artificial-star" method, outlined by Harang and Tønsberg[3], were used entirely for the determination of the parallactic angle, altitude, and azimuth of each selected auroral point. The distance from Chesterfield to each auroral point was calculated, while the corresponding height and distance to the projection of the auroral point on the Earth's surface were found mechanically.

The 200 parallactic photographs measured are typical of all the photographs that were taken. They are divided between the three photographic periods in January, February, and March, respectively, in about the same ratio as the total number of photographs for each of these periods. The same is also true of the distribution of auroral forms.

The height-versus-frequency curves of the lower auroral limits are shown in Figure 5. The various forms were divided into two groups: (1) Quiet arcs and bands without apparent ray-structure and (2) arcs and bands with ray-structure and draperies and forms with rapid movement. The number of points for each 2 km were counted—thus the altitude at 100 km includes the number of points at 99 and 100 km.

The distribution of heights is very similar to that found over Norway with a pronounced maximum for the quiet forms occurring between 104

[1] Skr. Vid. selsk. I, Mat.-naturv. Kl., No. 17 (1911).
[2] Geofys. Pub., **1**, No. 1 (1920).
[3] Geofys. Pub., **9**, No. 5 (1932).

and 106 km. The mean lower limit of the height of all quiet forms is 110.0 km which compares closely with the value of 107.9 km found by Vegard and Krogness[2] for the mean lower limit of all forms. If ray-
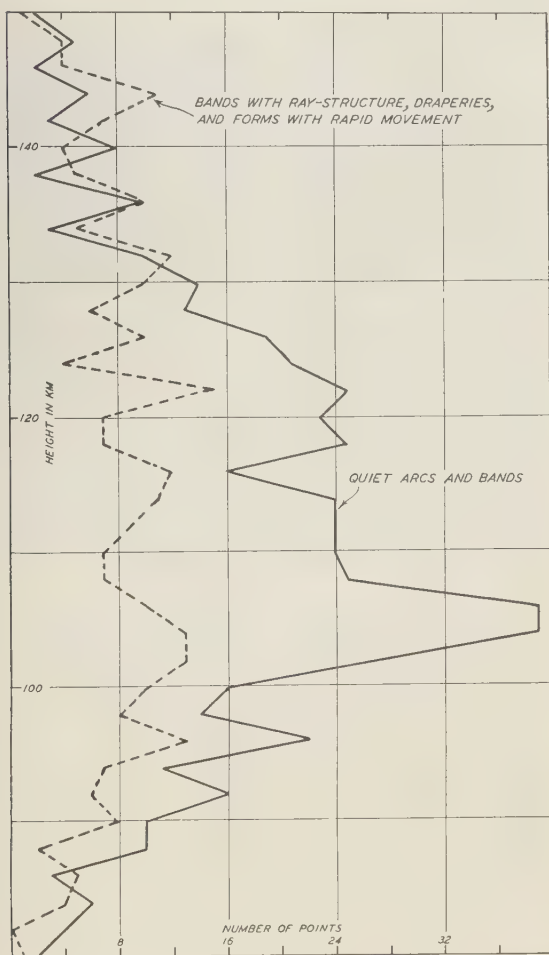

FIG. 5 —*DISTRIBUTION OF AURORAL HEIGHTS AT CHESTER-FIELD, CANADA, INTERNATIONAL POLAR YEAR, 1932–33*

and moving-forms are included the mean value is increased to 115.6 km, but this is largely due to an increase in the mean height of ray-forms during the March period.

Low values corresponding to the low values obtained by Alty and Wilson[4] at Saskatoon, Canada, were not found, the lowest measured

[4]Nature, 133, 687-688 (1934).

value being 71 km. High values for forms with ray-structure occurred mostly during March and were associated apparently with the proximity to Chesterfield of the sunlit region of the Earth's atmosphere at that time of the year.

Figure 4 shows a typical case of sunlit aurora, the break at the shadow-line between the sunlit aurora and the aurora in the shadow being quite apparent. A few cases were found where the height-measurements showed rays projecting short distances into the sunlit region, but this result may possibly be due to errors in the height-measurements.

The directions of the arcs and bands were found by projecting their lower edges on the Earth's surface. The angle between the westward end of each projected form and the southward-extending meridian from the magnetic-axis point was measured graphically. The mean value of the angle for 134 bands and arcs is $98°.7$. Values deduced by Vegard[5] from observations at neighboring stations during 1882-1883 are: Fort Rae $106°.1$; Kingua Fjord $67°.54$; Nain $101°.8$; and Godthaab $80°.1$.

From October 1, 1932, to March 31, 1933, fifty-one nights had so little cloud that auroræ of any extent would not have been hidden.
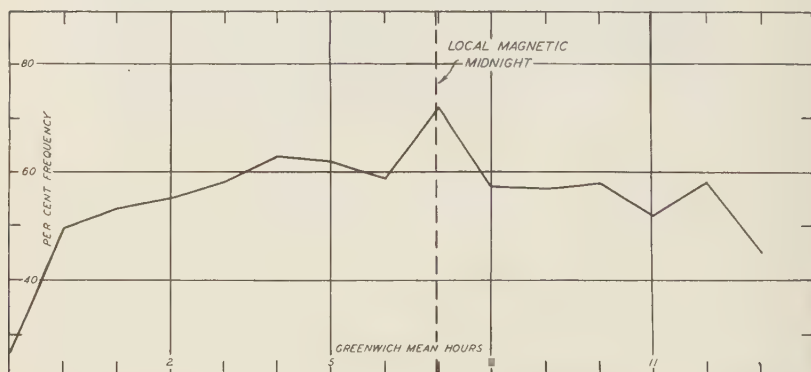

FIG. 6—NIGHTLY VARIATION IN NUMBER OF AURORAL FORMS FOR CLEAR NIGHTS ONLY, CHESTERFIELD, CANADA, INTERNATIONAL POLAR YEAR, 1932-33

Auroræ were seen on all except four of these nights. Figure 6 shows the nightly variation of all forms based on the fifty-one clear nights. The percentage-ratio of the number of times auroræ were observed within five minutes of the hour to the possible number of observations for that hour is plotted against the corresponding hour as abscissa. A maximum value occurs at $01^h 00^m$ local mean time or $07^h 00^m$ Greenwich mean time. The occurrence of a maximum in the auroral activity at this time is emphasized, if the number of auroral forms, their intensity, and the amount of sky covered by the auroral display at each hour are considered. This time is practically at *local magnetic midnight* for Chesterfield. Quiet arcs and bands predominate in the early evening hours and forms with ray-structure just before daylight in the morning.

⁵Phil. Mag., **42**, 47-87 (1921).

Some typical auroral forms are shown in Figure 7.

A detailed report of this work is to appear in the publications of the Meteorological Service of Canada on the observations and results of the

FIG. 7—TYPICAL AURORAL FORMS PHOTOGRAPHED AT CHESTEPFIELD, CANADA, INTERNATIONAL POLAR YEAR, 1932-33
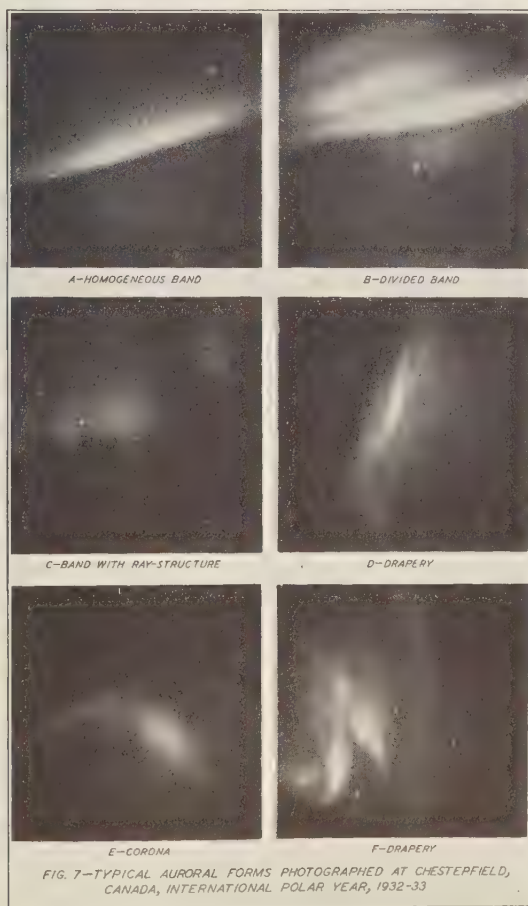
Canadian stations participating in the International Polar-Year programme.

To F. T. Davies, who was in charge of the Canadian party at Chesterfield, largely belongs the credit of the successful observational and photographic auroral programme. He was also the camera man at Chesterfield for all parallactic photographs.

METEOROLOGICAL OFFICE,
    Toronto, Canada

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REVIEWS AND ABSTRACTS

CORLIN, A.: *Cosmic ultra-radiation in Northern Sweden.* Ann. Obs., Lund, No. 4, 1934
(113+81). 30 cm.

A noteworthy contribution to the literature on cosmic radiation has been presented in this work by Dr. Corlin. Outstanding in the paper is a complete account of the development of the entire problem of cosmic radiation through the past two decades, which, in spite of occasional innuendo, appears rather free from bias. The inclusion by the author of the observational data he has used in the study is another meritorious feature which warrants imitation by others.

Although the purpose of the paper is to present Dr. Corlin's interpretation of the measurements of the cosmic radiation made in northern Sweden from 1929 to 1933, an entire section of it is devoted to a discussion of the well-known effects of meteorological conditions on the cosmic-ray intensity. In the course of this digression, a repetition of the mathematical development of the theory of multiple correlation is printed which causes one to wonder if the underlying principles of statistical analysis have been somewhat beclouded by elaborate mathematical symbolism. At least the section is impressive.

The author has sought relationships between cosmic-ray intensity and terrestrial-magnetic disturbances but found none which he could consider statistically reliable. The presentation of this negative evidence is highly desirable, although it is necessary to recognize that the comparisons were based on the magnetic records from Abisko only. Furthermore, the existence of a relationship between terrestrial-magnetic activity and cosmic radiation might be more readily discovered in the region where the Störmer exclusion-principle begins to appear owing to the magnetic fields assumed to exist in outer space during magnetic storms.

For some of the data the author finds a surprisingly high correlation, namely, $+0.81 \pm 0.05$, between the intensity of the cosmic radiation and the daily flocculi figures. This high correlation the author admits may not be real but due to similar seasonal trends in the two variables. If this is true, of course, the error ascribed to the correlation coefficient can have no significance and should never have been set down.

Carrying the apparatus down into an iron mine and obtaining measurements at different levels, a depth-versus-intensity curve was obtained. At a depth of 500 meters of water-equivalent an increase in the intensity was observed similar to that obtained by Clay at a depth of 250 meters in the Red Sea. A certain portion of the cosmic radiation was found capable of penetrating to a depth of 700 meters of water-equivalent. The presence of a large amount of radioactive material in the walls and the air of the mine made it difficult to obtain accurate measurements but great care was taken to eliminate errors from this source.

A. G. McNish

ALLEN, C. W.: *Atmospheric potential-gradient observations at the Commonwealth Solar Observatory, Mount Stromlo, Canberra.* Canberra, Mem. Commonwealth Solar Obs., v. 1, No. 4, 1934 (47 with 9 figs.).

In this memoir is given a description of the site, apparatus, and routine for recording the potential gradient at the Commonwealth Solar Observatory, Mount Stromlo, Canberra, Australia. At Canberra, the measurement of the potential gradient has been in progress since March 1925. In December 1925 the apparatus was moved from Hotel Canberra to a permanent observatory at Mount Stromlo. Results of measurements during six years (1927-32) are presented and discussed. From the results, it is concluded that: (1) No large secular change in the potential gradient has taken place during the last six years; (2) the annual variation-curve shows a single maximum which occurs during August; and (3) local meteorological conditions are chiefly responsible for the diurnal variation for selected days, the time of maximum occurring three hours after sunrise. The diurnal variation assumes a form similar to the "world-wave" on days of continuous winds.

The gradient shows no regular correlation with wind-velocity but is low during times of calm weather. This may be explained on the basis of electrode-effect. The gradient increases with poor visibility when southeast winds are blowing but not during northwest winds. It was also found to decrease with an increase in cloudiness.

These results coming from a part of the world where atmospheric-electric observations are rare, will be especially welcome to those engaged on investigational work in this field.

G. R. WAIT

A MECHANICAL-OPTICAL METHOD OF REDUCTION OF PAIRS OF AURORAL PLATES

By S. Chapman

(1) In this paper a new method is suggested for the reduction of the great number of pairs of auroral plates that have accumulated during the Polar Year, and will continue to be obtained in future. The existing methods of determining the height and geographical situation of the aurorae require plate-measurement and mathematical calculation. There should, it would seem, be some mechanical-optical method which, despite a possibly considerable initial cost for the equipment needed, would in the long run save much time, labor, and money. The impulse to think out such a method came from suggestions made to me by Dr. la Cour, at Brussels in July 1934 and, more effectively, at London in September 1934.

(2) The method here described seems in principle to be the simplest possible because it is a direct reconstruction, on a reduced scale, of the original situation of cameras and aurora at the time of the simultaneous photographic exposures. Doubtless the proposals are capable of being improved considerably in important details. If the method seems worthy of consideration and trial by those directly concerned with auroral work, it should perhaps receive the attention of the Executive Committee of the International Association of Terrestrial Magnetism and Electricity. Possibly the necessary apparatus might be constructed at the charge of the Association, for international use at some appropriate center, where auroral plates might be sent from any country, for reduction by a small staff specially trained and practised in this work.

(3) Consider two simultaneous photographs of an aurora taken at two stations. Let

A_1, A_2 be the optical centers of the lens-systems of the two cameras, at the instant of exposure,

$2d$ be the rectilinear distance A_1A_2,

O be the point which bisects the straight line A_1A_2 (it is approximately at depth d^2/D below the Earth's surface, where D denotes the Earth's diameter),

ON be the horizontal northward line through O,

hp be the horizontal plane through O,

ϕ be the azimuth of A_1A_2 relative to ON,

t be the sidereal time, at O, at the instant of photographic exposure (this is readily found, with the aid of an ephemeris, from the standard time of the observation, and the longitude of O),

a be the altitude of the Earth's axis at O, that is, the colatitude of O.

At the time t the celestial sphere has an orientation defined by a and t, relative to the plane hp and the line ON. The optical axes of the cameras (by optical axis is meant the line through the lens-center and the center of the photographic plate) will be in certain directions $A_1L_1{}_\infty$, $A_2L_2{}_\infty$; here L_1L_2 denotes the common perpendicular to the two axes, which in general will not intersect. But if the cameras are well-directed on

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the same aurora, L_1L_2 should be small compared with A_1L_1 and A_2L_2; in this case the aurora itself will be in the region around L_1L_2, unless the "parallactic" angle between A_1L_1 and A_2L_2 is small, in which event the aurora may be much nearer or farther than L_1L_2.

(4) The stars and even the aurora being very distant from the cameras, these will be focussed on infinity. But the distance A_1A_2 must be comparable with the distances from A_1 and A_2 of identifiable points $P, Q, \ldots$ of the aurora, if the photographs are to give reliable results. The practically parallel beams of light reaching A_1 from the stars $S, T,$ $\ldots$ whose images are shown on the plate, and from the points $P, Q,$ $\ldots$ of the aurora, have directions $A_1S, A_1T, \ldots, A_1P, A_1Q,$ $\ldots$ which are slightly inclined to $A_1L_{1\infty}$; likewise the beams A_2S_2 $\ldots, A_2P_2 \ldots$ are slightly inclined to $A_2L_{2\infty}$. The beams $A_1S,$ A_2S are parallel, and also $A_1T, A_2T, \ldots$; but A_1P, A_2P are not parallel, but intersect at the finite point P; likewise for other auroral points.

(5) The main features of the geometrical situation at the time of photographic exposure can be readily reproduced on a reduced scale. At any suitable place C we represent

hp by the plane hp' horizontal at C,

O and ON by a point O' and line $O'N'$ in hp',

A_1, A_2 by points A_1', A_2' in hp', at equal distances d' from O', in azimuths $(\pi+\phi)$, ϕ relative to $O'N'$,

$A_1L_{1\infty}, A_2L_{2\infty}$, in known directions relative to hp and ON, by $A_1'L_1'_\infty, A_2'L_2'_\infty$ in the same directions relative to hp' and $O'N'$.

The reduced reproduction can be achieved optically by placing the photographic plates in projectors p_1, p_2, the optical centers of whose lens-systems correspond to the points A_1', A_2'. It is convenient to suppose that the two cameras are identical, and likewise the projectors; the linear distances between corresponding pairs of star-images on the two plates will then be identical, while the linear scales of the auroral images will be inversely proportional to A_1R, A_2R if R is the center of the aurora. If the focal lengths of the cameras are not identical, there must be a corresponding difference in the focal lengths of the projectors, which should however still be identical in other respects.

The projectors should be capable of orientation in any direction, the center of rotation coinciding with the optical center. They should be supported on three points, resting on geometrical three-point bearings.

(6) The following method may prove useful for setting the projectors in the appropriate directions. Let the stars which are capable of being photographed on the auroral plates taken at any relevant auroral station be represented on the internal surface of a rigid framework, representing the celestial sphere (or a part of it).

Actually the surface need not be strictly spherical, but might be made up of conical portions if this were a more convenient construction. The framework should be capable of rotation about an axis corresponding with that of the actual celestial sphere, and there should be a divided circle enabling the sphere to be set at any hour-angle; the axis also should be adjustable in a vertical plane (whose horizontal projection is parallel to $O'N'$) and should have a divided arc enabling the axis to be set at the altitude α relative to the horizontal plane at C. Thus the sphere can be

rotated about its center O'' and set in the same orientation relative to the horizontal plane hp' and the same direction $O'N'$ as that of the actual celestial sphere relative to hp and ON.

Below the center O'' of the sphere let there be a horizontal three-point bearing b (point, groove, and plane) so placed that when either of the projectors rests upon it, the optical and mechanical center coincides with O''. The projector p_1, with the plate taken at A_1 inserted in it, is placed on b, and the light-beam from it is focussed on the surface of the sphere; its orientation is then adjusted so that the projected star-images coincide with their representations on the sphere. The projector is now oriented with the lines $A_1'S'$, $A_1'T'$, . . . and also $A_1'P'$, $A_1'Q'$, . . . in the desired directions. The whole projector, with its circles clamped, can then be removed and placed on an identical horizontal three-point bearing b_1, having the same orientation as b relative to $O'N'$; the orientation of p_1 will be preserved in such removal. The proper orientation of p_2 is obtained in like manner, with the aid of a second bearing b_2. The bearing b_1 may be fixed, and the bearing b_2 movable (without change of orientation, by means of two horizontal slides in perpendicular directions, or otherwise); or the bearing b may be dispensed with, and b_1, b_2 in turn moved along slides into the position O''. The distance $A_1'A_2'$ is adjusted to represent the distance $2d$ on a scale suitable in the circumstances (probably varying with the value of d itself and with the distance of the aurora relative to d). Likewise the *azimuth* of $A_1'A_2'$ is given its appropriate value ϕ relative to $O'N'$.

(7) The geometrical situation of the stations and of the directions of the light-beams is now reproduced; but the focus of each projector still needs to be adjusted, to give coincident images of the identifiable points P, Q, . . . of the aurora from the two projectors. If the aurora consisted simply of one luminous point P, the corresponding light-beams $A_1'P'$, $A_2'P'$ from p_1 and p_2 would intersect in a point P', to which the foci would be adjusted. Usually the image will be less definite, and a fine adjustment of focus will not be possible. In some cases the adjustment may have to be altered for different parts of the aurora, if these are at greatly different distances. If the aurora is diffuse and consists of light-sources spread throughout a volume, it is not possible to gain a very accurate idea of its situation, form, and size from only two photographic stations. If it consists of a luminous sheet (not necessarily plane) without ray-structure, the position and orientation of the different parts of the sheet can be ascertained, more or less exactly according to the size of the parallactic angle A_1PA_2 and the excellence of the photographs, by holding a deformable sheet (for example, of white paper) in the region common to the two beams from p_1 and p_2, until (after suitable adjustment of the focus of each) the best fit of the two images of different parts of the aurora is obtained. If the aurora has ray-structure, or other notable features, this location of the distribution of auroral light will be much facilitated. Possibly it might be found helpful, in obtaining this fit of the two images, if the light-beams were made to differ in color or if blink or flicker attachments were fitted to the projectors. In any case, when the best fit of the two images has been obtained, the reduced representation of the aurora can be marked by the ends of vertical rods, of suitable length and rising from suitable points to the plane Rp'. Their positions can be measured and the height and geographical situation of the

aurora thus determined: in stating the height, allowance for the curvature of the Earth can if necessary be readily made, the correction being a simple function of the horizontal distance of the aurora from the point on the surface of the Earth vertically above O. Simple tables can be constructed, for different latitudes of O, to give the latitude and longitude of points along the aurora, at known distances and on known azimuths from O.

(8) It would probably not be difficult to devise a means whereby to indicate in the reduced representation of the auroral situation the position of the cylindrical boundary between the shadow of the Earth and the space traversed by the Sun's rays: the most convenient method might be an optical one, using an adjustable cylindrical sheet of light. This would be of value in showing whether or not the aurora was, in whole or part, illuminated by the Sun's rays.

(9) The size of the sphere, and the detailed construction of the equipment, are matters for careful consideration, but will not be discussed in this preliminary proposal. A brief comparison may, however, be made between the present method and the methods of calculation at present used. In the latter the uncertainty inevitable in such reductions is concentrated at the very outset of the work, when points on the two plates are chosen as corresponding to the same point of the aurora. After this stage all is accurate measurement and careful calculation; but the initial uncertainty may be such that much of this later exactitude is, if not wasted, at least excessive. In the mechanical-optical method here proposed, the identification of common points in the two auroral images is made at the last possible stage, when the geometrical situation has been reconstructed; it would seem that at this stage the degree of accuracy of the results to be obtained from the two photographs could be more clearly judged than with the former method, and the probable inaccuracy of the measures of the located points of the aurora could be estimated and stated while recording the actual measures. This would perhaps be advantageous.

First Note added October 23, 1934.—Dr. G. C. Simpson has pointed out to me that the projectors will reproduce images of the two photographic plates in the image planes p_1, p_2 of the two projectors, and that outside these planes there will be no focussed light. This has drawn my attention to the fact that the proposed reduced representation of the original auroral and photographic situation does not reproduce exactly (on a smaller scale) the original *optical* situation for each camera. The aurora in all its parts may be considered as at infinity so far as concerns the original cameras, which must be focussed as if the light from each auroral point P_0 came as a parallel beam. But in the reduced representation the rays of light from the projectors will intersect at quite a small distance – a few meters at most – from the projectors, which must therefore be focussed to give images at this distance, and not at infinity. Let P_1 and P_2 be the images of the auroral point P_0 on the two plates. If the projectors had pinholes O_1, O_2 instead of lenses, from the point P_1 on one illuminated plate there would proceed a ray of light P_1O_1P which would intersect the corresponding ray P_2O_2P from P_2 on the other plate at a point P in space, which on the reduced scale would occupy the position of the auroral point P_0. The distances O_1P, O_2P would in general be different, so that if the pinholes at O_1, O_2 were replaced by lenses with

optical centers at O_1, O_2 these lenses would need to be focussed differently to give point images of P_1 and P_2 at P. Such focussing could always be achieved for any one auroral point P_0. But other auroral points P_0', P_0'' would correspond to points P', P'' in the "reduced space" which would in general not lie in the image planes p_1, p_2 containing P. The projectors would give focussed point-images of P_0', P_0'' at points P_1', P_1'' on p_1, and P_2', P_2'' on p_2, such that O_1P_1', O_2P_2' would pass through P', and likewise O_1P_1'', O_2P_2'' through P''. A screen passing through P would contain a point-image of P_0, but in general no one screen could give point-images of more than three points P_0, P_0', P_0'' (since in general a plane cannot pass through more than three given points), and even these three points could not in general be simultaneously in focus. Thus the identification of different parts of the aurora, using the beams of light from the two projectors, involves adjustments of focus of the projectors, different for different parts of the aurora. These adjustments may however be rendered unnecessary in practice by making the projector-lens small, so that it approximates to a pinhole, and by making a corresponding increase in the power of the illumination. If an aurora consisted of a distribution of discrete luminous points, then with good photographs, taken at stations far enough apart to give an adequate parallax, the identification of the corresponding points in the reduced space should not be too difficult. But aurorae actually are continuous distributions of light, and the determination of their form by means of the projector-beams will be correspondingly more difficult. If the aurora has a marked ray-structure it should be possible, with good photographs, to determine fairly approximately the situation and inclination of the rays, by getting different parts of each ray in focus successively. The same might apply also to fairly sharp edges of auroral curtains not possessing ray structure. For diffuse aurorae only a rough determination of position would be possible; but in this case the computational method could likewise give only rough results, because of the uncertain choice of corresponding points on the two plates.

Second Note, added October 26, 1934 Dr. Bartels has pointed out to me that methods of this kind are in actual use for obtaining positions in plan, and heights, of points on the Earth's surface, from aerial photographs of the same area from different points. Doubtless many details of the construction and use of apparatus for the present purpose can with advantage be borrowed from existing practice in aerial topography. Dr. Bartels has seen a device consisting of revolving shutters before the projectors, causing the two images to be projected alternately; a perfect fit of height and position for any point of the landscape is recognized by the cessation of flickering, in the image cast upon a small white disc attached to a vertical rod capable of being moved up or down. He has also seen red and green color-filters used before the projectors, giving a stereoscopic effect when the images are viewed through red and green spectacles.

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NOTES

26. *Errata*—The following correction is to be made in the September number of the JOURNAL. On page 229 in the fifth line of paragraph (1) under section VI for "the southern solstice" read "the northern solstice."

The following correction is to be made on page 157 of the June 1934 number of the JOURNAL: In second last line of second last paragraph read "reduce" instead of "produce."

27. *Relative sunspot-numbers, 1749-1933*—With reference to the quotation from the "Bulletin for Character-Figures of Solar Phenomena" given on page 235 and to Table 2 on page 234 of the September 1934 number of the JOURNAL, it is to be noted that from 1917 to 1928, inclusive, the central surface of the Sun referred to was that part between meridians situated 30° on either side of the central meridian. Beginning in the year 1929 the central zone is defined as a central-circle zone of a diameter equal to half the Sun's diameter.

28. *Personalia*—Dr. *David Stenquist*, Chief of the Bureau of the Swedish Telegraphic Service, died September 8, 1934, at the age of 59 years. Dr. Stenquist took part in investigations of terrestrial magnetism and electricty, and the JOURNAL has had the privilege of publishing a number of his papers. He devoted attention particularly to the study of earth-currents. Since the formation of the International Union of Geodesy and Geophysics, he has attended each one of the five Assemblies with the exception of the last one at Lisbon. In 1932 he took part in the Electrical Congress held in Paris. His last work, published in the Journal des Observateurs (Vol. XVII, No. 5, p. 71, 1934), was entitled "Sur la séparation des causes intérieures et extérieures (aimant ou courants) du magnétisme terrestre."

Sir *Edgeworth David*, emeritus professor of geology at the University of Sydney, Australia, died at Sydney, August 28, 1934, at the age of 76 years. In addition to his geological researches in Australia, Sir Edgeworth is known for his exploratory work in Antarctica, having participated in Shackleton's expedition of 1907-09, in the course of which he led the first sledge-journey toward the South Magnetic Pole. His masterpiece dealing with the geology of Australia, on which he had been engaged since his retirement in 1924, was nearly completed at the time of his death.

Professor *Stefan Hlasek-Hlasko*, formerly director of the Pavlovsk Observatory, of the Magnetic Observatory at Tiflis, and of the National Meteorological Institute of Poland, died October 21, 1934, after a long illness, at Wilno.

Rear-Admiral Dr. *F. Spiess* has been appointed President of the Deutsche Seewarte in succession to Vice-Admiral H. Dominik, who died on September 15, 1933.

The Royal Society of London has awarded a Royal Medal to Professor *S. Chapman* for his researches in the kinetic theory of gases, in terrestrial magnetism, and in the phenomena of the upper atmosphere.

Stuart L. Seaton, of the Department of Terrestrial Magnetism, sailed from New York November 15, 1934, for Watheroo, Western Australia, where he will join the staff of the Magnetic Observatory operated by the Department at that place. He will pay especial attention to ionospheric research. En route he will call on various officials in Australia who are interested in the work in which he will be engaged.

Dr. *John A. Fleming* has been appointed Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington effective January 1, 1935.

Professor *V. Carlheim-Gyllensköld*, vice-president of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, and widely known for his researches in terrestrial magnetism, died suddenly on December 13, 1934, aged 75 years. We hope to publish an account of his life and work in the March 1935 number of the JOURNAL.

REPORT OF IONOSPHERE-INVESTIGATIONS CONDUCTED AT COLLEGE-FAIRBANKS, ALASKA, DURING THE WINTER OF 1933-1934

By J. A. Fleming

Abstract—The investigations of the ionosphere begun at Fairbanks, Alaska, during the Second International Polar Year were continued during the winter of 1933-1934. Continuous automatic registrations of ionosphere virtual-heights on a frequency of 2050 kc were made. The equipment, as modified for this work, is described. The transmitter and receiver were operated at separate locations until February 10, 1934, when they were moved to College, Alaska, and further modified for side-by-side operation.

A typical record is illustrated. Tabulated values of virtual height during the morning show that, following the appearance of the critical frequency, the virtual heights fall rapidly to an average value of about 210 km, identifying the layer returning reflections on this frequency as the *F*-layer.

The periods during which reflections are returned and the times of critical frequency are shown. The usual morning increase in ionization is shown to be associated with sunrise, and from these data it is deduced that the ionizing rays of the Sun must be absorbed below a certain limit in the atmosphere when they are directed parallel to the surface of the Earth. The decrease in ionization in the afternoon is associated with time of sunset, but is not as regular. Reflections are observed most frequently near sunrise and sunset, indicating increased absorption near noon. *E*-layer reflections are seldom observed, and then only at night, indicating that the maximum ionization of the *E*-layer is not sufficient to prevent penetration on 2050 kc.

Comparison of the ionosphere-data and the magnetic records at the College station is made. The magnetic disturbances usually occurred at night. There was a strong tendency for the usual morning reflections to fail to appear during or following a magnetic disturbance. A striking improvement in the character of the records with side-by-side operation is noted and records obtained under such conditions are shown.

As a part of the program of ionosphere-investigation during the Second International Polar Year, stations equipped for continuous registration of ionosphere virtual-heights were located in and near Fairbanks, Alaska. Upon the completion of the Polar-Year work, it was decided to continue the investigations for another year with the support of the Navy Department, the Signal Corps of the United States Army, the Alaska Agricultural College and School of Mines, and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. With the departure of H. B. Maris, under whose supervision the Polar-Year investigations had been conducted, the active supervision of the work was taken over by the Alaska Agricultural College and School of Mines and observations extended through the winter of 1933-34. With the cooperation of President C. E. Bunnell of the College, these investigations have been directed by Professor V. R. Fuller, with the assistance of Corporal Marcus of the Signal Corps. Following the preliminary analysis of the records by Professor Fuller, the data have been tabulated and assembled by L. V. Berkner and Stuart L. Seaton of the Department of Terrestrial Magnetism. It is the purpose of this report to present these data.

The equipment used for these investigations is essentially the same as that used during the International Polar Year and described in the report of the International Polar-Year investigations by Dr. Maris. The description of this equipment as modified by Messrs. Fuller and Marcus for the present work is abstracted from the latter's manuscript report compiled upon the completion of this work.

The transmitter is of standard oscillator-amplifier type and is capable of a power-output of 150 watts. A piezo-controlled master-oscillator furnishes excitation for a type-860 tube and this in turn drives two type-860 tubes in parallel in the final stage. A standard doublet-type antenna-system provides effective high-angle radiation for the signal. When this equipment is set up for side-by-side operation of the transmitter and the receiver, it is necessary to use an ordinary master-oscil-

lator, directly keyed, because the crystal is, of course, too sluggish to respond to the short pulse. A continuously working oscillatory-circuit in the vicinity of the sensitive receiving-apparatus is thus eliminated.
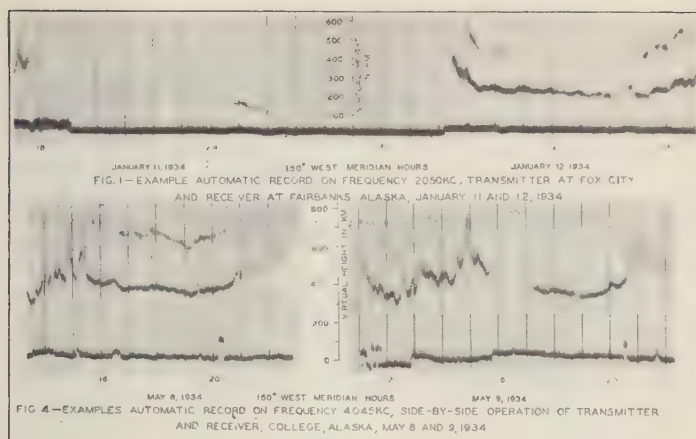
The method of pulsing was designed by Dr. Maris. A neon-tube is used in a relaxation-circuit, the frequency of which can be easily controlled. A variable resistor allows close adjustment of the time-constant of the circuit and pulses in the order of 0.0005 second are easily obtained. This circuit operates a type-'10 tube and is synchronized from the 60-cycle, alternating-current main.

For receiving, a standard superheterodyne receiver is employed. This is equipped with a single stage of resistance-coupled audio amplification and a type-247 tube is used in the output. A specially designed radio-frequency amplifier is connected ahead of the receiver and together these two units furnish a sensitive arrangement for the reception of the echo-signals. A single-wire, inverted L-type antenna is used for receiving.

The recorder, designed by Dr. G. W. Kenrick, employs a neon-lamp, which obviates the necessity for a rectifier in the receiver-output circuit. The direct-current voltage is adjusted to a point just below the breakdown-voltage of the neon gas. In this connection, the tube is most sensitive to the incoming signals. The signal-voltage serves to light the tube, and, with the receiving and the transmitting equipment operating on the same power-line, the neon-recorder and the neon-pulser are synchronized. The optical path consists of an achromatic lens focussed on the sensitized paper, with a mirror driven by a synchronous motor interposed to distribute the beam across the paper. The camera carrying the sensitized paper is clock-driven and makes one complete revolution in 24 hours. For visual observation, a ground glass is placed beside the recording camera.

Synchronism of the equipment was originally made possible by so locating the equipment that power was obtained from the same source. During the early winter, the transmitter was located at Fox City, Alaska, about ten miles from Fairbanks, while the receiver was located in the offices of the Weather Bureau in the Federal Building at Fairbanks. Difficulty was experienced in proper maintenance of the equipment with this separation. In addition, severe phase-changes occurred between the two ends of the line because of the sudden heavy loads thrown on the lines by the gold dredges at Fox, causing severe shifts in the base-lines of the records. It was further desirable that some multi-frequency records be obtained to augment the single-frequency recording. For these reasons, and because of the imminent probability of failure of power-supply due to the winter shutdown of the mining activities, it was deemed desirable to locate both the transmitter and the receiver at College, Alaska, where they would be available for more detailed research. The equipment was therefore out of operation from February 10 to May 8, 1934, during which time it was moved to College and readjusted for side-by-side operation.

Except for a few records obtained on 4045 kc, operation for this period was entirely confined to 2050 kc. A sample record on this frequency is shown in Figure 1. The records for the period of operation on this frequency prior to February 10 are summarized in Figure 2. In this Figure, periods are indicated during which reflections were observed and the critical frequencies are shown. Because some difficulty was experienced in operating the receiver at high sensitivities, it cannot be considered certain that no reflections were present during the periods in which no reflections were recorded, although this must have been the case during at least part of the time.

FIG. 1—EXAMPLE AUTOMATIC RECORD ON FREQUENCY 2050KC, TRANSMITTER AT FOX CITY AND RECEIVER AT FAIRBANKS ALASKA, JANUARY 11 AND 12, 1934

FIG. 4—EXAMPLES AUTOMATIC RECORD ON FREQUENCY 4045KC, SIDE-BY-SIDE OPERATION OF TRANSMITTER AND RECEIVER, COLLEGE, ALASKA, MAY 8 AND 9, 1934

The values of virtual heights observed during the mornings on which reflections were returned are tabulated in Table 1. This Table shows that following the appearance of reflections, the virtual height falls rapidly to values averaging about 210 km, indicating the passage of the critical frequency upward through 2050 kc. Not much variation in the virtual height is observed for a period of several hours after the lowest value is reached. Virtual heights correspond closely to the virtual heights of the *F*-layer observed at other locations. The general absence of large fluctuations in virtual height during the daytime indicates the absence of any additional daytime *F*-region strata up to the ionization represented by 2050 kc. It also appears from Table 1 that the retardation of the reflection in lower layers cannot be very great during the periods in which the virtual height is relatively constant, indicating that the region of maximum ionization is above 200 km.

The appearance of reflections in the morning with the associated critical frequency, as illustrated in Figure 2, appears to be a definite function of time of sunrise. Figure 3 gives the time of sunrise and sunset at various heights calculated for the upper limb of the Sun, disregarding atmospheric refraction, at College, Alaska. It is immediately apparent that a curve adjusted to the times of appearance of the critical frequency does not correspond to the time or shape of the curve at the ground for sunrise. It can be seen, however, that there is a good correspondence in shape with the curves for sunrise above 50 km. It seems probable that the time required for the ionization to rise to 2050 kc varies somewhat with season, depending upon the minimum ionization reached. It has been shown at other stations that the rise of ionization is very rapid after ionization commences, so that this factor will cause only a small time-difference during the short period embracing these data, and will act to bend the curve toward earlier time in the summer. This indicates a fit with about the 40- to 100-km curve. Because the maximum ionization must actually be above 200 km, it is seen that sunrise at this height probably occurs some time before ionization commences, as is the case in the lower latitudes. It appears, therefore, that the Sun's rays active in ionizing the *F*-layer must be filtered out in the lower atmosphere. It may be shown (see appendix) that to a first approximation if sunrise occurs at a height h above the Earth at a certain time, the Sun's rays tangent to an imaginary shell at a height k above the Earth will reach a point y above h at the same time according to the relation
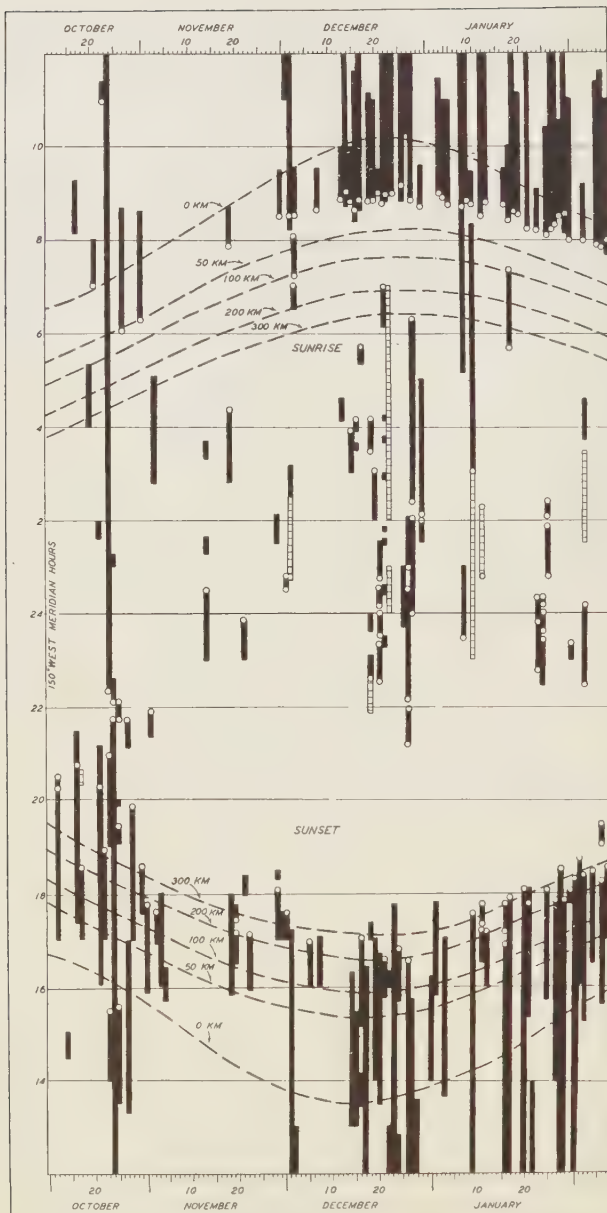
$$k = (y - h)$$

FIG 2—TIME LIMITS AND CRITICAL FREQUENCIES RECORDED REFLECTIONS IONOSPHERE ON
FREQUENCY 2050 KC, FAIRBANKS, ALASKA, 1933–1934

▭▭▭ = E-LAYER REFLECTIONS   ▬▬▬ = F-LAYER REFLECTIONS   o = CRITICAL
FREQUENCY —OTHERWISE REFLECTIONS DISAPPEAR WITHOUT PASSING THROUGH CRITICAL
FREQUENCY   —·—· = TIMES SUNRISE AND SUNSET AT VARIOUS HEIGHTS ABOVE EARTH

TABLE 1—F-layer heights in kilometers on frequency 2050 kc during mornings, Fairbanks, Alaska, 1933-1934

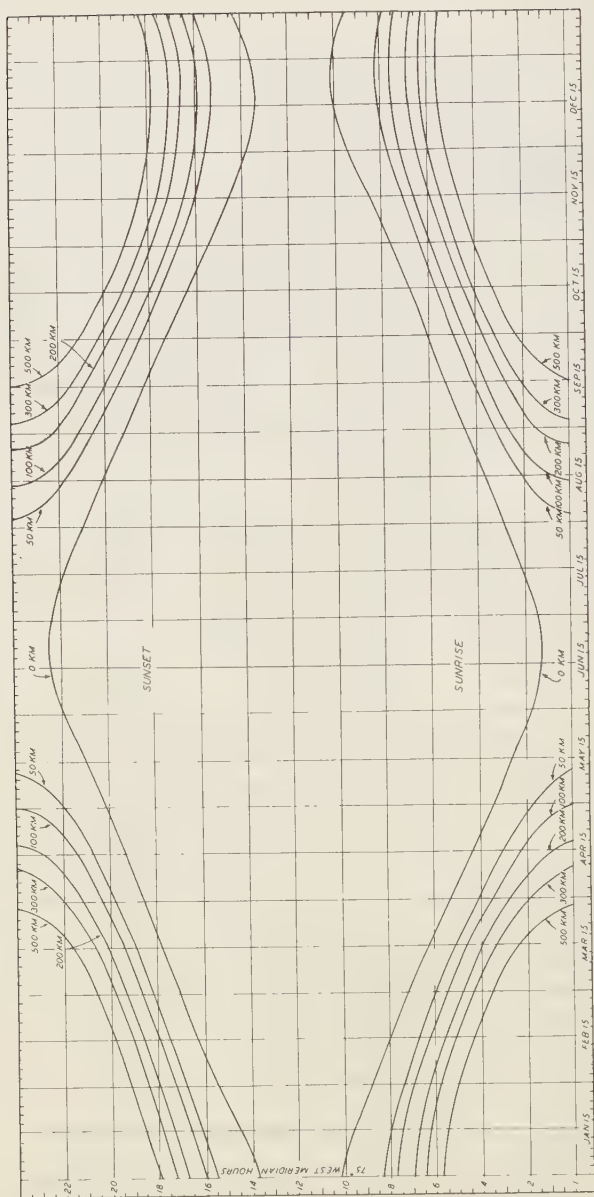| Date	150° west meridian time																
	6:00–6:15	6:15–6:30	6:30–6:45	6:45–7:00	7:00–7:15	7:15–7:30	7:30–7:45	7:45–8:00	8:00–8:15	8:15–8:30	8:30–8:45	8:45–9:00	9:00–9:15	9:15–9:30	9:30–9:45	9:45–10:00	10:00–10:15
1933																	
Oct. 17										250	212	212					
21	225		200		287		250										
24	400		337	237	225	275	212										
27	225		200	237			212	225									
31									212	312	250	287	225	237	225		212
Nov. 19									412	400	350	262	250	237		212	212
30											337	325	287	212			200
Dec. 2											412	325	262	225		212	187
8											350	275	250	225	237	212	200
13											337	300	262	225	212	212	
14											412	287	250	287	237		200
15											350	337	312	250	250		212
16											300	287	237		212		212
17											400	362	262	250	225	200	
19													337	250	237	225	212
20											425	325	325	300	250	237	200
21												375	275	275	212	200	200
22												387	262	250	212		200
23												287	262	250	188	188	200
24												375		237			
26													250	237			225
28														212	237	225	200
1934																	
Jan. 4											750	350	275	300	250	237	212
5												375	250	225	212	212	200
8											400	387	250	212		225	200
9												350	250	200		200	200
12										337	337	287	237	225			
13										400	350	287	287	237		212	237
18										325		275		187		200	
19										337	287	237		237			
20										387		237					
22										375	300	262					
24											275	250		212		212	212
26											400	262	262	225	200		200
27										375	287	225	237	250			
28										312	250	250		225			
30											225	200					
31												200					
Feb. 3								350	500	250		200					187
6								312	325	237		212					
7							350	350	262								
8						275		300									
11				287	225												

FIG. 3 – CALCULATED TIME OF SUNRISE AND SUNSET (DISREGARDING ATMOSPHERIC REFRACTION) AT COLLEGE, ALASKA, FOR VARIOUS HEIGHTS ABOVE THE EARTH

Putting $y = 210$ km and $h = 40$ to 100 km, we have $k = 110$ to 160 km, giving very roughly a lower limit below which the portion of the Sun's rays active in ionizing the F-layer cannot penetrate the atmosphere parallel to the Earth's surface. Although this treatment is only qualitative because of the unsatisfactory assumptions which must be made, it may be pointed out that if multi-frequency observations giving the exact time of the commencement of ionization can be made available through-

out the year at high latitudes, certain important data concerning the structure of the upper atmosphere can be obtained. This study is particularly applicable to high latitudes because of the difference in the forms of the curves of sunrise with different heights above the Earth due to the rapid change of azimuth of the Sun with sunrise at the different heights.

The data of Figure 2 show that on the average the critical frequency decreases to a value of 2050 kc earliest in the afternoon during midwinter, and progressively later as sunset occurs later. There is a much greater variation in the time of critical frequency in the evening than observed in the morning, indicating some irregularities in the ionization, or the rate of recombination, of the *F*-layer during the daytime, such as have been observed in the temperate zones by other investigators.

It must be noted that reflections are frequently observed near sunrise and sunset. As was previously remarked, the absence of reflections during midday may be frequently attributed to insensitivity of the receiver. On most occasions, however, the height of the recorded trace diminished and gradually disappeared toward midday without reaching a critical value, returning in the reverse manner in the afternoon as in Figure 1. This indicates that attenuation of the signal becomes much greater during this period.

Reappearance of reflections at night is shown by Figure 2 to occur quite frequently. It is notable, however, that practically no reflections at night were observed from the time of the evening critical-frequency to about 21^h in the winter and upon reappearance, with a few exceptions, were observed entirely after midnight. The absence of reflections during the early evening can hardly be accidental and must be a factor in any theory which would account for the reappearance at night of reflections.

On a few days, reflections were observed from virtual heights of 100 to 160 km, corresponding to *E*-layer heights. Such reflections were mostly observed at night as shown in Figure 2. It is apparent that when reflections were returned during the daytime, the recording frequency (2050 kc) must have been well above the *E* critical-frequency.

Through the courtesy of N. H. Heck of the United States Coast and Geodetic Survey, the data of the Fairbanks Polar-Year Magnetic Observatory have been made available for comparison with the ionosphere-observations. The magnetic data include the character of the day, the times within which disturbances were apparent, and the range of these disturbances in magnetic vertical intensity (Z). Although we hesitate to conclude there is any direct correlation between the character of the ionosphere-records and magnetic disturbances because of the possibility that the absence of reflections in the former may be frequently due to apparatus difficulties, certain interesting information is apparent.

In summarizing the magnetic data it may be said that in general the period was relatively undisturbed, with only one severe disturbance lasting throughout a complete day. In general, disturbances were confined to the night, usually starting after 22^h and, with few exceptions, ending before sunrise. Some of these disturbances were quite severe for short periods. There was also a distinct tendency for severe disturbances to be repeated from night to night for several nights. This is most notable during the winter of 1933-1934 for the periods of October 11 to 15, November 3 to 10, December 2 to 7 and 8 to 9, and December 31 to January 3. Each of these periods is marked by an absence of echoes during these days, and, in the case of the most severe periods of November 6 to 10, and December 2 to 7 and 8 to 9, no reflections of note appear for two or three days thereafter. Table 2 gives more detailed information concerning coincidences of reflections and magnetic disturbances.

TABLE 2—*Summary of occurrence of observed reflections from the ionosphere at Fairbanks and of recorded magnetic disturbances at College, Alaska, October 10, 1933 to February 9, 1934*

Group-ing	Item	No. of days
A	Total observed..	122
	Daytime-reflections observed...................................	76
	Magnetic disturbances of character 1 to 2 recorded..............	46
B	Both reflections and magnetic disturbances observed.............	23
	No reflections but magnetic disturbances observed...............	23
C	Total F-layer reflections observed at night.....................	37
	F-layer reflections observed at night during recorded magnetic disturbances...	10
	Total E-layer reflections observed at night.....................	7
	E-layer reflections observed at night during recorded magnetic disturbances...	2
D	Total days reflections not observed about sunrise...............	63
	Magnetic disturbances recorded simultaneously or on the night preceding non-appearance sunrise-reflection.................	36
E	Total days reflections not observed about sunset................	63
	Magnetic disturbances recorded simultaneously or during the night following non-appearance sunset-reflection.............	24

The data under A and B of Table 2 show that if the days on which reflections are returned are compared with the days of magnetic disturbance there is only a chance correlation. Likewise a comparison of the nights during which E-layer and F-layer reflections appear respectively with the days of magnetic disturbance shows a chance distribution. From the data under D, however, a definite effect is apparent. It is found that the expected appearance of F-layer reflections at sunrise does not occur on about one-half of the days recorded. Of these days 36 are preceded by a magnetic disturbance. Then of the 46 days which were magnetically disturbed, 36 or about three-fourths were followed by a non-appearance of normal morning F-layer reflections as against about one-half for a chance distribution, while of the 59 days which showed normal morning reflections, only 10 or one-sixth were preceded by magnetic disturbances as against about two-fifths for a chance distribution. This appears to be significant. A similar comparison of magnetic disturbances with reflections preceding them shows only a chance correlation. It is indicated, therefore, that the magnetic disturbances were usually followed by a cessation of F-layer reflections for several hours. It should be noted in this connection that a mere comparison of the days of some reflection and of disturbance are not sufficient to make the correlation apparent, but that the hours within which the disturbance occurred are necessary.

Since commencement of side-by-side operation of the equipment, the character of the records is greatly improved. Two records obtained under such conditions on a frequency of 4045 kc are shown in Figure 4 for May 8 and 9, 1934. Discontinuance of this work was necessitated by the shut-down of the power-plant at College shortly after this time so that only a few such records are available. Because of the great detail shown in the records obtained with side-by-side operation, and the possibility that multi-frequency data can be obtained with the equipment under the control of a single operator, it is hoped that this work can be resumed at College upon the resumption of operation of the power-plant. It may be expected that under these conditions the data can be greatly enhanced.

Appendix

Calculation of time of sunrise for points in the ionosphere above the Earth's surface—In Figure A let h be the height of a point above point P which is just reached by the rays of the upper limb of the Sun, tangent to the Earth at point Q. Refraction of the Sun's rays in the lower at-

mosphere (amounting to about 35' at sunrise) is not included in this calculation as it has been shown that rays passing through the lower atmosphere are not active in ionizing the upper atmosphere behind it. Then

$$R/(R+h) = \cos\ POQ = \cos\gamma$$

By similar triangles, γ is the depression of the Sun's upper limb below the horizon at P. Then, assuming the semi-diameter of the Sun to be

Fig A

16' of arc, $(\gamma+16') = a$ is the negative altitude or depression of the Sun at P. This value may now be substituted in the usual spherical triangle for the calculation of hour-angle, giving sunrise (or sunset) of the upper limb of the Sun without refraction in local apparent time, namely

$$\tan t/2 = \sqrt{\cos s \sec(s-p) \sin(s-a) \csc(s-\phi)}$$

where a is the altitude (entered with the proper sign), ϕ is the latitude, p is the polar distance (or 90° minus Sun's declination), and $s = (a+\phi+p)/2$. The result may be transformed to mean time by applying the equation of time and for general use may be corrected to the standard meridian time used.

Knowing the time of sunrise at height h above point P, it is now required to find the height k of a spherical shell above the Earth's surface of radius $(R+k)$ such that rays tangent to this shell at point Q' at the same time will just appear at a point P' directly above P and distant y from P. Given γ corresponding to a predetermined value of h, rays tangent to a sphere of radius $(R+k)$ will reach P' at a height $y = (x+k)$ above P. Then

$$(R+k)/(R+k+x) = \cos\gamma$$

Substituting $\cos\gamma = R/(R+h)$

$$(x+k) = [(R+h)\ (R+k) - R^2]/R = h+k+hk/R$$
$$y = (x+k) = h+k\ (1+h/R)$$
$$k = (y-h)\ [1-h/(R+h)] = (y-h) - (y-h)\ [h/(R+h)]$$

If $h < (R+h)$, the value of k may be written to a first approximation

$$k = (y-h)$$

For values of $h = 300$ km, the approximate form gives values of k about five per cent too high.

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NOTES

28. *Instrumental developments.*—The United States Coast and Geodetic Survey and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington are making a joint attack on the problems of more rapid and convenient absolute magnetic observations and of more consistent performances of variometers for vertical intensity at observatories.

The Carnegie Institution of Washington sine-galvanometer has been installed at the Cheltenham Magnetic Observatory. The program includes exhaustive tests of existing instruments and development of new ones. For the Coast and Geodetic Survey, H. E. McComb, George Hartnell, Ellis A. Johnson, and D. L. Parkhurst, and for the Department of Terrestrial Magnetism, S. E. Forbush, A. G. McNish, H. F. Johnston, and C. Huff are taking active part. Mr. Johnson is taking up electrical methods of recording, with the special aim of a combination of accuracy, rapidity, and convenience which has not as yet been attained by other methods. The program also includes the study of all developments in various fields that may have a bearing on the instrumental requirements.

29. *Compass-testing stations in United States.*—The United States Coast and Geodetic Survey is determining magnetic declination at compass-testing stations of airports. These stations usually consist of a circular concrete platform on which radial lines are painted so that the plane can be placed accurately in any desired direction. The lines usually start with magnetic north and are spaced for each 30° thereafter. Another method used consists in setting a pelorus on the upper wing and taking bearings on a distant object whose magnetic bearing has been previously determined. Such work has already been done by the Coast and Geodetic Survey at San Francisco and Chicago airports and by Civil Works Administration state representatives of the Coast and Geodetic Survey, Professor C. J. Tilden of Yale at various Connecticut airports and Professor Kissam of Princeton at six airports in various cities of New Jersey.

The magnetic bearings of river ranges are being determined for possible use of the mariner in obtaining compass-deviations on those ranges. This involves the determining of the true bearings of the ranges and also sufficient observations of declination to cover possibility of local attraction.

30. *Cosmic-ray work in North America.*—Dr. *Thomas H. Johnson*, of the Bartol Research Foundation, has returned from a three months' trip to Colorado and Mexico which was undertaken for the purpose of measuring the east-west asymmetry of the cosmic radiation at various elevations and latitudes. Extensive observations were made at Mt. Evans and Echo Lake in Colorado and at Nevado de Toluca, Villa Obregon, Vera Cruz, and Parral in Mexico. The survey was a continuation of that begun last year as a part of the program authorized by the Cosmic-Ray Committee of the Carnegie Institution of Washington and it was financed from that Institution. Dr. Johnson was assisted by Lewis Fussell, Jr.

31. *Cosmic-ray work in South America.*—Plans for the study of cosmic rays from Mount Tupungato, a 19,680-foot Andean peak on the Argentine frontier, have been announced, according to *The New York Times*, by Director Julio Bustos of El Salto Observatory. The directors of the National Bureau of Standards and the Astrophysical Observatory, Washington, D. C., are expected to aid the Chilean expedition.

32. *Conference of Directors.*—The Eighth Conference of Directors of National Meteorological Services, under the auspices of the International Meteorological Organization, will be held at Warsaw, September 5 to 12, 1935.

REPORT ON MEASUREMENTS OBTAINED AT THE HUAN-CAYO MAGNETIC OBSERVATORY (PERU) FOLLOWING THE PROGRAM OF THE SECOND INTERNATIONAL POLAR YEAR DURING MAY TO AUGUST 1933

By H. W. WELLS

The accompanying tables summarize the measurements made at the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington according to the schedule of the International Polar-Year program for ionosphere-measurements. This Observatory is located near Huancayo, Peru, in latitude 12° 02'.7 south and longitude 75° 20'.4 west at an elevation above sealevel of 11,000 feet. The equipment used was placed in operation during the latter part of April 1933, and the observations reported upon are therefore subsequent to that date. The transmitter and receiver are located side by side so that the transmissions are at vertical incidence.

Table 1 shows the results of the measurements on 4000 kc at noon and midnight according to the Polar-Year schedule "NM".

TABLE 1—*Results of ionosphere-measurements at noon and at midnight, Huancayo Magnetic Observatory, Peru, June to August 1933*

Date	75° west meridian mean time	Frequency	Virtual heights in km		Remarks
1933	*h*	*kc*			
June 7	12	4000	95*VRSpl*	200	About same amplitude
June 7	24	4000	. . .	265	Strong and single
July 12	12	4000	95*MVSpl*	205*BV*	
July 12	24	4000	. . .	290-335	Strong and split
Aug. 9	12	4000	115*MSV*	230*B*	
Aug. 9	24	4000	. . .	300*M*-370*BV*	

TABLE 2—*Results of hourly measurements on 4000 kc, Huancayo Magnetic Observatory, Peru, June to August 1933*

75° west meridian time	Virtual heights in km		
	June 21-22, 1933	July 26-27, 1933	August 23-24, 1933
h			
11	100*MVR*, 221*SV*-243*BV*	114*MVR*, 220*SV*-248*BV*	105-145*MVR*, 200*B*
12	100*MVR*, 225*BVSpl*	110*MVR*, 154*SVR*, 217*B*	115-145*MVR*, 185*B*, 225*SV*
13	100*MVR*, 192*M*, 250-275*BV*	115*MVR*, 210*SV*-230*BV*	110-145*MVR*, 215*S*, 250*B*
14	95*MVR*, 200*MVR*, 280*S*-310*B*	115*MVR*, 210*SV*, 300-330*MV*	108*S*, 233-285*MBV*, 330-350*MBV*
15	95*MVR*, 263*MVR*, 287*B*	115*MVR*, 273*MBV*, 400*B*	230-250*MB*, 335-372*MB*
16	95*SV*, 283*B*, 561*M*	Thunder-storm	315*M*, 360*B*, &*h*
17	. . . 266*BV*, &*h*	128*M*-148*M*, 290*B*, 568*MVSpl*	295*B*, &*h*
18	. . . 253*BV*, &*h*	310*B*, &*h*	245*B*, &*h*
19	. . . 268*B*, &*h*	150*M*-200*B*, 345*S*, 370*B*, 460*S*, 755*M*-785*M*, 1455*M*, 1500*M*	260*B*, &*h*
20	. . . 317*B*, &*h*	175*S*-220*M*, 375-415-450*M*, 665-700*S*, 860-900*S*, &*h*	260*B*, &*h*
21	. . . 268*B*, &*h*	325-364*B*, 642-762*M*, &*h*	295*B*, 340-415*BV*
22	. . . 264*B*, &*h*	255*B*, &*h*	335*B*, 600-740, &*h*
23	. . . 268*B*, &*h*	340*B*, &*h*	615-710-740*SV*
24	. . . 455*B*, &*h*	322-335-385-435*BV*, 585-635*SV*	None observed
01	670*B*, 740*M*, 790-995*S*, &*h*	283-333-373*SV*, &*h* to 570	None observed
02	410*B*, 665*S*, &*h*	255-295-345-390*SV*, &*h* to 580	None observed
03	95*SVR*, 727-887*SV*	185-240-305-375*SV*, &*h* to 540	None observed
04	90*MSV*, 345-395*S*, 1085-1140*S*	No observation	350*VyS*
05	120*SVR*, 320-355*S*, &*h* to 580*S*	335-405*M*	130*S*-160*S*, 260*VyS*
06	Interference	360-420*M*, 705-755, *S*&*h*	115*S*-170*S*, 06:30—325-425*MV*, 625-835*MBV*
07	90*MVR*	125*SVR*, 345*M*-390*B*, &*h* to 650-795*S*	280*B*, 560*M*
08	. . . 257-298*BV*	120-140-165*SV*, 290-328-362*BV*, 570-625-665*MV*	115*S*, 290*S*-315*B*, 570-630*MV*
09		107-122-173*MV*, 265*B*, 443*B*-515*S*, 535*B*-565*S*	125*S*, 250*MV*-310*B*
10		100-120-170*MV*, 235*B*-295*S*, 385*M*-420*B*	107-150*MVR*, 230*S*-255*B*
11		105-155*MVR*, 225*SV*, 255-295*M*	100-145*MVR*, 215*B* (single)

Table 2 shows the hourly measurements on 4000 kc according to the Polar-Year schedule "24".

Table 3 shows the values at noon of the E critical-frequency determinations according to the Polar-Year schedule "E".

Table 4 shows the values at noon of the F critical-frequency determinations according to the Polar-Year schedule "F".

The abbreviations used in the tables are as follows: B = large amplitude; M = medium or intermediate amplitude; S = small amplitude; V = varying amplitude; R = rapidly; $\&h$ = and scattered to greater heights; Vy = very; Spl = echos splitting.

TABLE 3—*Determinations at noon 75° west meridian time of E critical-frequency, Huancayo Magnetic Observatory, Peru, May to August 1933*

Date	E critical-frequency[a]
1933	*kc*
May 17	3550
June 14	3725
July 5	Questionable
July 19	3700
Aug. 2	3550
Aug. 30	Questionable

[a]Values are approximate as the critical fre-quency for the E-layer was not sharply defined.

TABLE 4—*Determinations at noon 75° west meridian time of F critical-frequencies, Huancayo Magnetic Observatory, Peru, August 1933*

Date	F critical-frequency			
	$f''F_1$	$f'F_1$	$f''F_2$	$f'F_2$
1933	*kc*	*kc*	*kc*	*kc*
Aug. 16	4260	4660	5290	5650

Note: The values of f_{F_2} appear unusually low.

A discussion based on much more extensive data obtained at the Huancayo Magnetic Observatory is given in the "Report of ionosphere-investigations at the Huancayo Magnetic Observatory (Peru) during 1933" by L. V. Berkner and H. W. Wells[1], and in two manuscripts "*F*-region ionosphere-investigations at low latitudes" by L. V. Berkner and H. W. Wells[2], and "Critical-frequency observations of the *E*-layer of the ionosphere at the Huancayo Magnetic Observatory" by H. W. Wells[3]. The latter two papers were communicated to the September 1934 meeting of the International Union of Scientific Radiotelegraphy.

[1]Proc. Inst. Radio Eng., **22**, 1102-1123 (1934).
[2]Terr. Mag., **39**, 215-230 (1934).
[3]Terr. Mag., **39**, 209-214 (1934).

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THE RELATION OF THE PACIFIC ECLIPSE OF JUNE 8, 1937, TO INVESTIGATIONS OF CHANGES OF IONIZATION OF THE IONOSPHERE

By L. V. Berkner

On June 8, 1937, there will be a total eclipse of the Sun of 7.1-minute duration at noon and visible over a path starting at Santa Cruz Island in latitude 11° south and longitude 166° east at sunrise, over the Pacific Ocean in latitude 10° north and longitude 131° west at noon, and in Peru in latitude 12° south and longitude 70° west at sunset. The total time of travel from the eastern to the western extremities of the path will be roughly 3-1/2 hours.

Exact details of this eclipse are not yet published, but the Nautical Almanac Office of the United States Naval Observatory has furnished sufficient information to determine the following approximate times, so that some idea of the relation of this eclipse to work on the ionosphere can be obtained.

The eclipse will be nearly total at Huancayo, Peru, with the minimum of the exposed disc at about $17^h 25^m$, 75° west meridian time, or about 20 minutes before sunset, the end of the eclipse occurring after sunset at Huancayo. Sunset in the ionosphere will of course be somewhat later. Farther west and north, at the Galapagos Islands (0°, 90° west) the eclipse will be about 90 per cent total at about $16^h 00^m$, 90° west meridian time ($17^h 00^m$, 75° west meridian time), with the end of the eclipse about an hour before sunset. Apparently the only other available land in the path is Christmas Island (2° north, 158° west), with 99 per cent totality at about $9^h 45^m$, 150° west meridian time ($14^h 45^m$, 75° west meridian time).

In outlining the ionosphere-investigations which may be conducted during this eclipse it is worth while to review briefly results during previous eclipses. The eclipses of 1925 in the United States and of 1927 in England preceded the development of suitable technique for numerical measure of changes in ionization. Observations, largely confined to signal-intensity measurements, indicated ionization due to ultra-violet light, but could not identify the regions thus ionized. The eclipse of August 1932 was more productive of results with observations in Canada by Rose and Henderson; at Sydney, Nova Scotia, by Gilliland and Norton; at Washington, D. C., by Kirby and Berkner; at Boston, Massachusetts, by Kendrick and Pickard, and by Mimno and Wang; and in New York by Alexanderson. Measurements were also made in Europe by Appleton and others to determine if a corpuscular eclipse was present.

Because of the advanced technique, numerical measurements of changes in ionization in the various layers were made by several investigators. This work established the fact that the greater portion of the normal ionization of the E- and F_1-layers was due to ultra-violet light. It was found, however, that the results of observations on the F_2-layer by Rose, by Alexanderson, and by the group of the National Bureau of Standards did not agree. The results of the last-named group showed no unusual

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decrease in F_2-layer ionization during the eclipse; the results of Rose showed some change at that time; while the results of Alexanderson by facsimile methods showed a decrease some two hours before the eclipse which he interpreted as a possible corpuscular effect. A detailed examination and discussion of the results of these groups led to some doubt as to the real cause of disagreement.

The difference between the results of Rose and the group of the National Bureau of Standards may have been due to a difference in technique, while in the observations of Alexanderson, which were made on only one frequency, the decrease observed may have been one of the erratic changes in the F_2-layer frequently observed in the daytime. The question brought up by these results cannot be considered as satisfactorily answered.

The work of Chapman, Appleton, and others prior to the eclipse of 1932 indicated that should there be an eclipse of neutral corpuscles displaced to the east of, and earlier than, the optical eclipse, it might be observed because of the comparatively low velocity of such corpuscles (estimated at 1600 km per second). It was suggested that such an effect might be observed in the E-layer. The effect was not apparent in the E- and F_1-layers, but the disparity of the results for the F_2-layer leaves this question open for this high region.

The F_2-layer, with its very high ionization and rapid and apparently erratic changes in ionization, presents one of the most difficult problems in the work on the ionosphere. New information concerning this problem would do much toward the advancement of understanding of these regions. Although work toward this end is now progressing along several lines, additional information such as could be obtained during an eclipse would be extremely useful, particularly in view of the discrepancies of the 1932 observations. Furthermore, with the advances in technique now taking place, much more detailed and exact information concerning the lower layers could be obtained, and confirmation of the 1932 effects might be sought. Further information as to the movement of the maximum ionization of the F_1-layer during the eclipse might be obtained, the data on which are very scant at the present time. This is particularly desirable because of the apparent relation this layer may bear to magnetic disturbances. The greater recombination-coefficients of the E-layer shown during the eclipse of 1932 should make possible the discovery, by employing the improved technique now available, of higher layers of lower ionization, which are ordinarily masked by the lower layers. It is desirable that calculations be made to determine whether a corpuscular effect in the F_2-layer could be determined from available points in the area of the eclipse. Because of the general eastward movement of the eclipse-path, approximately along the equator, it may be possible to make observations for both optical and corpuscular effects at the same point.

It is expected, of course, that the Huancayo Magnetic Observatory will take an active part in these observations because of its location just to the south of the belt of totality. It is unfortunate, however, that the eclipse will end after sunset at this point, resulting in a very great angle of incidence of the shadow.

It should be noted that the inhabited Charles Island (Galapagos) lies just to the north of totality. Because of its location on the opposite side

of the eclipse-band from Huancayo, it may be used in conjunction with Huancayo to check the discrepancies noted during the 1932 eclipse. This location is not subject to the disadvantages of the more easterly location at Huancayo from the standpoint of observations of the ionosphere. It was shown during the eclipse of 1932 that full totality was not necessary to obtain essential results.

It seems desirable that among such locations the calculations be made for Huancayo (Peru) and Charles Island (Galapagos) for 100 km, for 500 km, and for such other heights as may be necessary for interpolation, as well as for the path and time of a corpuscular eclipse assuming the corpuscles to be traveling at 1600 km per second.

It seems further desirable that a portable multi-frequency equipment be located at some point in the Galapagos designed to sweep the frequency-band returning reflections perhaps every ten minutes. Observations there with such equipment, together with the control automatic multi-frequency equipment at Huancayo, should lead to conclusive evidence concerning the changes in ionization. It may also be desirable to locate a manually controlled receiver and recording equipment at one station to receive and record the transmissions of the other. A program of signal-intensity recording across the eclipse-band would also provide useful information.

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ON THE PROPAGATION OF MAGNETIC STORMS

By J. Egedal

In a report presented to the Association of Terrestrial Magnetism and Electricity[1] of the International Union of Geodesy and Geophysics Professor A. Tanakadate has compiled the times of three sudden commencements of magnetic storms for more than twenty magnetic observatories distributed over the Earth. This material is of great interest for the study of the propagation of magnetic storms, especially on account of its homogeneity, arising from the fact that most of the instruments from the records of which the data have been derived, are of the same type (la Cour's quick-running magnetographs and "Variomètres de Copenhague").

The data given in Professor Tanakadate's report refer for all observatories to the "first maximal deviation," and only for a small number of observatories to the "very beginning" of the sudden commencement. For this examination only times for the "first maximal deviation" have been used.

The present examination of the propagation of the three storms is based on the assumptions that the storm was produced by electric particles coming from the Sun and that there may be real propagation of the storm in such a manner that the storm will travel gradually from one side to the other side of the Earth.

As to the question at which part of the Earth a storm will commence, S. Chapman[2] has shown that the storm will commence at some place on the Earth where the clock is 18^h. As a consequence the propagation from the afternoon-side to the morning-side of the Earth will be examined. The orbits of the electric particles will be altered by the magnetic field of the Earth (Birkeland, Störmer), and it therefore will be necessary also to examine whether a propagation from the day-side to the night-side of the Earth or vice versa should exist.

We suppose that the magnetic disturbance following the electric particles coming from the Sun will reach as far as to the center of the Earth at a certain hour T_0 and further that the time required for a propagation as far as the radius of the Earth on the average for the whole Earth is a. If then the sudden commencement of a magnetic storm is observed at a magnetic observatory at the hour T, and the zenith-distance of the Sun at that moment is Z, the following equation may be formed

$$T - T_0 + a \cos Z = 0$$

It should be added that the angle Z gives only approximately the angle which correctly should be used (parallax).

For this examination only times given to seconds have been used (except those for Ponta Delgada). In cases where times are given for more

[1] C.-R. Assemblée Lisbonne 1933, Union Géod. Géophys. Internat., Ass. Mag. Electr. Terr., Bull. No. 9, 149-157 (1934).

[2] S. Chapman, Solar streams of corpuscles, London, Mon. Not. R. Astr. Soc., **89**, 456-470 (1929).

than one magnetic element the earliest one has been taken. The quantity T_0 has been determined as the mean of the times of all sudden commencements of the storm considered. The quantity Z was determined approximately in degrees. From the equation formed for each storm the time-interval a and its mean deviation were derived by the method of least squares.

Thus the propagation in two directions in the ecliptic plane will be examined, namely, one from the Sun to the Earth and the other at right-angles thereto. We shall first consider propagation in the direction from the Sun to the Earth, that is from the day-side to the night-side of the Earth and then in like manner that in the direction at right-angles to this. Table 1 summarizes the mean times required in both cases for propagation through a distance equal to the Earth's radius.

TABLE 1 — *Mean times required for propagation through a distance equal to the Earth's radius*

Date	Number of times	Day-side to night-side	Afternoon-side to morning-side
Oct. 14, 1932	14	$+15^s \pm 34^s$	$+48^s \pm 21^s$
Apr. 30, 1933	21	$+10 \pm 9$	$+1 \pm 9$
May 29, 1933	15	$+12 \pm 13$	-15 ± 9
	Means	$+11 \pm 7$	-2 ± 6

It will be seen that the mean deviations of all values given in the Table are of the same order of magnitude as the values themselves.

To examine whether the times of the three magnetic storms considered depend on the magnetic latitude of the observatory at which they are observed[3], the times of each of the three storms were divided into three groups, one containing times from that third of the observatories in highest magnetic latitude, one containing times from that third of the observatories in intermediate magnetic latitude, and one containing times from that third of the observatories in lowest magnetic latitude. Table 2 summarizes for these groupings the mean magnetic latitudes and the mean departures from the mean of the times of the sudden commencements.

TABLE 2—*Mean magnetic latitudes and departures from mean times of sudden commencements for groups*

Storm of						Mean of all storms	
Oct. 14, 1932		April 30 1933		May 29, 1933			
Magnetic latitude	Depar-ture	Magnetic latitude	Depar-ture	Magnetic latitude	Depar-ture	Magnetic latitude	Depar-ture
$68°$	31^s	$71°$	-8^s	$67°$	-7^s	$69°$	5^s
55	-4	59	9	57	2	57	2
7	-28	2	-1	-2	4	2	-8

[3] *Cf.* L. A. Bauer and W. J. Peters, Regarding abruptly-beginning magnetic disturbances, Terr. Mag., **30**, 45-67 (1925).

It will be seen that the values from the different storms do not agree with one another; therefore the resulting values of "Mean of all storms" must be considered as uncertain.

With the above assumption it is concluded from the data compiled by A. Tanakadate: (1) It is not possible to draw from these data a definite conclusion as to the velocity of the propagation of magnetic storms; (2) it is not probable that the time required for a magnetic storm to travel from one side of the Earth to the opposite exceeds one minute.

In conclusion it should be remarked that the mean deviation found above certainly might be smaller were we to have data from more observatories and to examine doubtful values more closely. Chief improvement must be expected, however, through investigation of a greater number of magnetic storms and of the detailed features of each.

Copenhagen, Denmark

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By H. D. HARRADON
(See also pages 320, 332, and 350)

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CELEBRATION OF THE COMPLETION OF ONE-THIRD CENTURY OF CONTINUOUS OPERATION AT THE CHELTENHAM MAGNETIC OBSERVATORY

By N. H. Heck

A milestone in the progress of investigation of terrestrial magnetism in the United States was reached with the completion of a third of a century or three sunspot-cycles of continuous operation at the Cheltenham Magnetic Observatory at Cheltenham, Maryland, about 14 miles from Washington. The occasion was celebrated October 10, 1934, at the Observatory by addresses, demonstrations of field- and observatory-work and exhibits. The latter covered the entire range of activity and also collection of all types of compasses used on sea. on land, and in the air, and views of the various vessels of the United States Coast and Geodetic Survey which took part in the development of magnetic work at sea of the United States out of which grew the well-known ocean-surveys by the Department of Terrestrial Magnetism, Carnegie Institution of Washington.

The guests —175 in number—were from the Coast and Geodetic Survey, the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, the National Bureau of Standards, and the Naval Research Laboratory. There were three guests of honor, Dr. John A. Fleming, Acting Director, Department of Terrestrial Magnetism of the Carnegie Institution of Washington and Editor of the JOURNAL, Dr. J. Bartels, Professor of Geophysics at the University of Berlin and Professor of Physics at the Forstliche Hochschule in Eberswalde, Germany, and Research Associate of the Carnegie Institution of Washington, and Mr. Daniel L. Hazard, Senior Mathematician and Chief Magnetician of the Coast and Geodetic Survey.

Captain R. S. Patton, Director of the Coast and Geodetic Survey, sounded the keynote of the occasion in the following address:

"It is a special pleasure to welcome you here this afternoon, for a special reason with which you will all sympathize; to me this little group of buildings, simple and unpretentious as they are, stands as a physical symbol of one of the finest manifestations of human aspiration. I can say that to such a group as this, because you are here today in direct consequence of the fact that aspiration is the principal motivating force of your own lives. If these structures are the inanimate symbols, some of you are a part of the living reality of what I have in mind.

"The aspiration of which I am thinking is that will to penetrate farther into the unexplored regions of infinite truth, which manifests itself in fundamental scientific research. I can think of no worthier or more inspiring purpose to which one might dedicate himself. For, intrinsically, I think we may envy any man, whatever his material circumstances, whose dominant passion in life is to know truth. And, extrinsically, I think that Man's principal hope for the future, at least in this temporal, mundane sphere, is to be found in progress in that eternal struggle to bring him into closer and more harmonious relation to his environment, which is one of the objectives of scientific research.

"I am not going to elaborate on this idea, or preach to you a sermon about it. I mention it at all only because I have sensed that this meeting has an inner significance which lifts it above the plane of a mere pleasant social function. I think such a meeting as this partly would fail of its purpose if it did not enable us to withdraw for the moment to a vantage point from which our view of the forest was not obscured by the trees. We dare not lose that larger vision. The conduct of scientific research demands the exercise of an infinite patience which remains tolerable only for so long as we have the vision before us. To Mr. Hartnell, for example, who has devoted more than twenty years to the work of the Observatory, the task long since would have been unendurable if it had ever become merely a day's work for a day's pay.

"Our welcome to you today is particularly warm because you have helped us to retain that vision. The stimulating effects of our contacts with you; your problems on which you have enlisted our aid and conversely, those of our own which you have helped us to solve, all have contributed to that end. We want you to know that we value your friendship and cooperation and that we hope always to give as well as receive."

Captain N. H. Heck, Chief of Division of Terrestrial Magnetism and Seismology, gave the history of the work of the Observatory and outlined the accomplishments of the guests of honor as follows:

"This might well be considered a centennial since the first magnetic observations of the Coast and Geodetic Survey were made in Connecticut in May 1833. During one-third of this period the Cheltenham Observatory has been in continuous operation. This grew out of the earlier work near the close of the last century.

"The plan for a magnetic survey of the United States was prepared in 1899 by Dr. L. A. Bauer, then Inspector of Magnetic Work, Coast and Geodetic Survey. The plan included field-observations at every county-seat in the United States and the operation of a number of observatories throughout the United States and the regions under its jurisdiction. Prior to that time observatories had been maintained during 1860-66 at Key West, Florida, during 1876-80 at Madison, Wisconsin, during 1882-80 at Los Angeles, California, and during 1890-95 at San Antonio, Texas,— at the last two with the same Adie instrument that is still in operation— but all the series were too short to be entirely satisfactory.

"From the adopted plan came the present observatories at Cheltenham, Sitka, and Honolulu. The observatory started in 1903 at Vieques, was later moved twice, but care was taken to make the necessary observations to insure a homogeneous series for the region. The observatory of the original plan at Baldwin, Kansas, operated for control of field-observations in the middle west, was abandoned and the observatory at Tucson, Arizona, was established in 1909.

"In planning for an observatory near Washington, it was realized that in addition to the regular functions it would be necessary to provide a place for testing and comparing instruments and for carrying on investigations in cooperation with the Washington office.

"All these purposes were taken into account in selecting the site and designing the necessary buildings. It was also necessary to find a site free from present and future artificial disturbance with uniformity of

magnetic distribution over the area needed and with reasonable accessibility and ease in obtaining supplies. Unfortunate experience at San Antonio, Texas, and at many foreign observatories with the disturbing effects of electric cars made it necessary to give special attention to this consideration.

"After much investigation of possible sites, the present one was chosen. It is 14 miles from the National Capital and is part of the 800-acre farm of the House of Reformation for Colored Boys, an institution of the State of Maryland from which the site is leased. The site is remote from any source of artificial disturbance and, as a result, is as suitable today for magnetic work as when it was first chosen.

"The preparation of plans for the buildings and their erection was assigned to John A. Fleming, then Aid in the Coast and Geodetic Survey, and today with us in quite a different capacity. He had numerous unusual problems in operating two sets of recording instruments in the same building but far enough apart to avoid mutual disturbance. No magnetic material could be introduced and the building had to be insulated against temperature-changes at a time when none of the modern means of accomplishing this was available.

"The buildings were begun near the end of 1900 and observations began in April 1901. Their unbroken continuity (except for a few hours) has in itself made an important contribution to the value of the work. Standards have been maintained during the entire period so that the work of the Observatory is known throughout the world and it is frequently referred to in literature on the subject.

"The Observatory was first under the charge of Walter G. Cady, now professor of Physics at Wesleyan University; next followed L. G. Schultz, who later had charge of an observatory of the Argentine Republic and still later returned to the United States to erect the no longer existing magnetic observatory of the Weather Bureau at Mount Weather near Bluemont, Virginia. Then came W. F. Wallis, now of the staff of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and then J. E. Burbank who did useful early work in the study of microseisms or minute earth-tremors. George Hartnell took charge in 1911 and continued to the present year when Lieut. Comdr. Eoline R. Hand was placed in charge, Mr. Hartnell remaining at the Observatory to carry on important investigations in instruments and methods. S. G. Townshend, Jr., except for a short period of duty at Baldwin, Kansas, has been assistant observer continuously since 1903.

"During the long period of observation, the plant as a whole has had several narrow escapes. A severe bolt of lightning has passed through this highly inflammable variation-building without damage except the shattering of a flagpole on the building. A tornado removed part of the roof. The most serious menace developed within the past few years from the activity of an enemy which had no regard for scientific accomplishment. This was the small insect known as the termite. He found the combination of wood and sawdust much to his liking and was well prepared for a comprehensive attack in millions which would soon have rendered the buildings not only unsuited to their purpose but actually unsafe. Emergency and public-works funds were made available. The office-building which you are now in, was rebuilt and new foundations were placed under the adjacent variation-building. A new compari-

son-and-test building replaced a very small one which was moved to another site and which will soon be used for continuous cosmic-radiation observations at the request of the Committee of the Carnegie Institution of Washington which deals with that subject. The pier-arrangements of the various buildings were modified to meet present needs with the advice and assistance of Dr. Fleming and his staff.

"Much cooperative work is done here. In 1922 The Association of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union, asked that each country designate an observatory for making measurements to maintain the international magnetic standard. In 1923 the American Geophysical Union asked that this function be performed jointly by the Cheltenham Magnetic Observatory and the Magnetic Laboratory of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. While the latter— the Department of Terrestrial Magnetism— has the responsibility of establishing the standard and of making international observations to maintain it, it is now obliged to make its observations for the United States almost entirely at Cheltenham, because of the encroachment of the city of Washington on its present site. There are many other cooperative observations with the Carnegie Institution of Washington. The Naval Research Laboratory has frequently made use of the favorable magnetic conditions at Cheltenham for various investigations. The National Bureau of Standards from time to time makes precise measurements of our instruments in connection with the work in international standards, it has given assistance in problems relating to magnets and has aided in other ways. In return it makes use of the records of the Cheltenham Observatory to control investigations being carried on in its laboratories.

"The uses of Terrestrial Magnetism in the United States are too numerous to mention here. The exhibits show that needed information is furnished for all mariners' charts and aviators' maps. The Cheltenham records are particularly used in connection with problems of radio transmission, the records being duplicated weekly for the benefit of the National Bureau of Standards and the research-department of one of the large broadcasting companies. Other communication companies and the Naval Research Laboratory require similar duplication from time to time.

"We have today three special guests and I wish to say a little about each. Dr. John A. Fleming started his career in magnetic work in the Coast and Geodetic Survey and built the Cheltenham and Honolulu observatories. In this work he showed the efficiency, zeal, mastery of details, and executive ability which have characterized his work ever since. He was the loyal assistant of Dr. Bauer during the years of establishment of the country-wide magnetic work of the Coast and Geodetic Survey, during the organization of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and during the development of the ocean-surveys from the time when Dr. Bauer and Captain Faris started the magnetic observations of the United States at sea to the building and extensive voyages of the *Carnegie*. His accomplishments are too numerous to mention. His present important duty tells the story in itself. He has always shown a cooperative spirit and the close relations of his organization and our Survey in the field of terrestrial magnetism are in themselves responsible for much joint accomplish-

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ment. He played an important part in the Second Polar-Year program, not only through the work of his organization but through developing support so that the necessary appropriations were forthcoming which made possible the participation of our Survey and other governmental agencies. His work as editor of the JOURNAL is an important contribution to Terrestrial Magnetism. He is now president of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics.

"Dr. J. Bartels, Research Associate of the Carnegie Institution of Washington, is present not only as an outstanding figure among world magneticians, but he represents the scientific Germany to which this Observatory and magnetic work in general owes so much. The method of obtaining the horizontal intensity was developed by Gauss 100 years ago. A little later Weber developed the earth-inductor. The large absolute instruments in this building were built in Germany and also the Eschenhagen variometers of which you will see one set not in use, while the others are closed from view today so that the work of the Observatory will not be interrupted. Adolf Schmidt has made many contributions which we utilize daily. Dr. Bartels has made and published many important investigations and not the least of his services has been his contributing with Angenheister an important chapter on the magnetic field of the Earth to the *Handbuch für Experimentalphysik.*

"Daniel L. Hazard, Senior Mathematician and Chief Magnetician of the Coast and Geodetic Survey entered the service in 1892. He served under Mr. Schott in what was then the Computing Division until 1899, when he entered the magnetic work of the Survey with which he is associated not only in Washington, but in the minds of magneticians all over the world. He has been almost entirely on office work though he spent about a year on field-work in early days, made observations during the solar eclipse of 1900, and instructed officers of the *Patterson*, *Blake* and *Bache* in magnetic work. He is perhaps best known for his *Directions for Magnetic Measurements* which is in use throughout the world. When a revision was called for some years ago he was asked to make the instructions apply to the southern as well as northern hemisphere, the request coming from international sources. One of his great contributions has been in using his ripe judgment to secure the best values of the magnetic elements when the instruments go wrong. They should not do so, but we are pursuing a very small physical unit—the gamma· and very small instrumental changes make trouble. Little has been lost, however, because of Mr. Hazard's ability to deduce the most probable value. His knowledge of magnetism throughout the United States is profound and he has put the information in systematic and convenient form for all citizens who desire to make use of it.

"In conclusion I wish to ask you to use your imagination and to look beyond these strictly utilitarian buildings and instruments to the fact that we are dealing with one of the fundamental and elusive forces of Nature. In our geodetic work we measure another fundamental force— gravitation—but this once measured remains the same at the same place. In magnetism we cannot predict today what to-morrow will bring forth. In this struggle for a better understanding of this fundamental earth-science the Cheltenham Observatory is in the front line of attack."

The three guests were then called upon. Dr. Fleming called attention to the fact that from the first Dr. Bauer stressed the international character of the work and in this both he and Dr. Bauer, in the organization and development of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington since 1904, found the work of the Coast and Geodetic Survey indispensable. The important cooperation between the two organizations, has ever become closer and more effective during the past few years and plans for the future will bring about greatly increased results from this cooperation.

Dr. Bartels brought congratulations from across the sea. He said that to many an observatory was a place where something very special was going on, that is, that there is something specially distinctive about the Earth's magnetism in its locality. This is of course not true but rather it is a place where instruments are available and measurements are made with care. He stated that scientists across the sea feel gratitude for the careful planning and excellent work of the Coast and Geodetic Survey extending over so large an area of the Earth's surface and also for the fact that the records are not jealously guarded but are made available to all who can use them, in the form of excellent publications.

Mr. Hazard expressed his satisfaction that after disturbances incidental to building operations, the Cheltenham Observatory is now restored to normal operation. Opportunity is now afforded to Mr. Hartnell to study the theory of instruments and methods of observing and the cooperative work that is planned should bring out further improvements. It may be expected that the work will go on for many years without disturbance and with increasing efficiency. He pointed out that the study of the Earth's magnetism by the Coast and Geodetic Survey, implanted by Hassler, and kept growing by Schott for nearly 50 years, took on a new lease of life beginning with Bauer and the more generous appropriations provided from 1899, and branched out and developed rapidly under Bauer's careful planning and initiative. This is now beginning to bear fruit and we can look forward confidently to an increase in value of the crop with every year of its growth.

UNITED STATES COAST AND GEODETIC SURVEY,
Washington, D. C.

B—Terrestrial and Cosmical Electricity

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SUMMARY OF THE YEAR'S WORK, DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE IN-STITUTION OF WASHINGTON

By J. A. Fleming

The work of the Department during the report-year, July 1, 1933, to June 30, 1934, may be generally grouped under four divisions of endeavor. These were: (1) Reduction and study of the observational material already gathered; (2) development of methods and technique to obtain continuous records of the electrical conditions and their variations in the ionosphere; (3) continued attack in the laboratory on basic phenomena of magnetism through experimental work in nuclear physics; (4) maintenance of field-operations to preserve continuity of secular-variation material and of records at observatories for seasonal, diurnal, and irregular fluctuations of the Earth's magnetic and electric field.

Perhaps a most significant immediate advance is that in the ionosphere-research which was initiated by the Department in 1925. In its latest development, it appears the most promising of recent methods of approach and one greatly enhanced by the rapid progress in nuclear physics and in wave-propagation. It is not at the stage where continuous photographic records may be secured, manual observational methods meanwhile having shown fundamental results. This method appears also a sure means to obtain definite information not only of the conditions of the, as yet, otherwise inaccessible regions above the Earth's surface but of cosmical phenomena and of their relations to terrestrial ones. An understanding of the mechanism connecting the ionosphere and the external portion of the Earth's surface must improve knowledge of the relation of cosmical radiations in the ionosphere to their images represented by magnetic and electric phenomena at the Earth's surface and below the Earth's surface.

The results obtained and progress made in the investigational and experimental work are summarized briefly below.

TERRESTRIAL MAGNETISM

The average state of the Earth's magnetic field varies from day to day, reflecting apparently in the main solar activity. A leading problem is to correlate various measures of magnetic activity and of solar activity. Investigations of these were made for the years 1931 and 1932 in continuation of earlier work (see Terr. Mag., vol. 37, 1-52, Mar. 1932). The characteristic lag of terrestrial-magnetic activity behind solar activity occurring before a sunspot-minimum was confirmed. A shift in the standard of international magnetic character-figure (C) was found by comparing the frequency-distribution of days with $C = 0.0$, 0.1, 0.2, etc., up to 2.0, within the two triennial intervals 1909 to 1911 and 1930 to 1932, both of which intervals have the same average for the u-measure of activity and represent similar conditions holding near the end of a sunspot-cycle. The essential feature was found to be an increase in the

number of days with character-figures $C = 1.1$ to 1.7, from 190 days in the first interval to 300 days in the last interval, indicating a tendency, on the part of the observatories, to report character 2 more often than formerly. This shift in the standard of C was discussed and appears not to seriously impair the value of C for those purposes for which it was introduced. The study of the relations between various measures of terrestrial-magnetic activity and of solar activity was supplemented by using Brunner's series of monthly means of the profile areas of the solar limb-prominences in the years 1910 to 1932; this measure of solar activity was found only slightly, if at all, superior to the ordinary relative sunspot-numbers.

A report on methods of recording and measuring solar activity was prepared for the Lisbon Assembly of the International Union of Geodesy and Geophysics in September 1933, summarizing the measures, observations, and records of solar activity mainly used for comparison with geophysical phenomena, and discussing their relative merits with regard to the study of correlations between solar and terrestrial phenomena.

The study of horizontal-intensity changes of the Earth's magnetic field in relation to annual values of magnetic activity to vertical-intensity changes was extended. It was found that a small but, nevertheless, apparently real correlation exists between the annual values of the vertical magnetic force at various magnetic observatories and the annual values of magnetic activity. During magnetically disturbed years, the vertical force tends to be higher than during quiet years, even at Sitka, Alaska. This, in conjunction with a similar finding for horizontal intensity, is interpreted to denote that the external magnetic field of the Earth undergoes an 11-year periodic change, having a maximal value during magnetically disturbed years.

The "secular," seasonal, and diurnal distributions of 151 sudden commencements at Watheroo during 1919 to 1930 were examined and were found to be more common during active years than during quiet years, to be more frequent during local summer, and to exhibit a preference for the afternoon hours although they may occur at any time of the day. These observations are interpreted as evidence that a complex of two or more causes is operative in sudden commencements, one terrestrial and the other extra-terrestrial. The former is believed to be associated with the condition of the ionosphere which explains the seasonal and diurnal distributions, while the other is associated with the cause of magnetic storms and explains the secular distribution.

A possible test for theories of magnetic diurnal-variations and magnetic storms was suggested. One of the three outstanding theories for diurnal variations requires a current-sheet in the lower regions of the ionosphere above which the normal magnetic diurnal-variations should be reversed. A crucial test would be a measurement of the magnetic changes above that region. Magneto-ionic double reflection of radio waves gives a measure of the magnetic field at the point at which reflection takes place. If a sufficiently accurate determination of changes of the magnetic field throughout the day can be accomplished by the study of radio-reflections, definite information on the theory would be forthcoming. Information on the location of the seat of the currents flowing during magnetic storms may be obtained in the same manner.

The relative magnitudes and the directions of the first large change

that characterizes the sudden commencement of some magnetic storms were calculated and drawn as vectors in stereograms. These show the relative magnitudes and directions of the change in the Earth's field $\triangle R$ and its vertical component $\triangle Z$ for six sudden commencements as found from the magnetograms of 30 magnetic observatories fairly well distributed over the globe.

There appeared to be but one systematic geographic distribution, which, however, was quite obvious. This was the general direction of $\triangle R$, which was northerly everywhere except in an around the north polar regions and not far from horizontal everywhere including the polar regions. There was no notable systematic distribution of its vertical component, $\triangle Z$, either in its sign or in its magnitude. The sign of $\triangle Z$ remained the same, positive or negative, at some observatories for the six sudden commencements. There are some indications that a more dense distribution of observatories might reveal regional distribution of positive and negative $\triangle Z$ with vanishing values between them.

The interpretation or scaling of data of magnetograms, however, was always satisfactory, especially in regard to the strict correspondence of $\triangle H$, $\triangle D$, $\triangle Z$ in many cases. Sometimes these appear to be *not* simultaneous; again $\triangle D$, and $\triangle Z$ do not begin and end with the abruptness that characterizes $\triangle H$. Sometimes the spot of light appears to halt or even reverse its motion several times in what was selected as the large change. These features may be brought out probably more forcibly and possibly with some significance were the magnetograms reduced to one common scale, which can be accomplished now with the new photographic bench. When this has been done, it will be possible to show miniatures of the characteristic features of the sudden commencements in stereograms of world distribution. It is apparent that the generally used low sensitivity of the D- and Z-scales, however, hide the small features that might be seen if the sensitivity were of the same order as that of H. The $\triangle Y$-component has not yet been drawn in stereograms.

The average force-change of the principal movement of these sudden commencements was studied and compared with the mean disturbance-vector, represented by the vector-difference of the quiet-day and disturbed-day magnetic fields. The data, arranged in seasonal groups and as a yearly average, showed that the two vectors are almost diametrically opposed for each seasonal group and for the year, and that they are in the plane of the Earth's geomagnetic axis but not parallel to the axis.

Some time was also devoted to the investigation of a peculiar type of magnetic disturbance frequently noted on magnetograms from polar stations and designated by Birkeland as "polar elementary storms" and by Chree as "the Antarctic special type of disturbance." An investigation of the lunar diurnal-variations at Huancayo is also in progress, results in declination for the southern summer (November to February) for the years 1922-30, having been completed. These show the lunar diurnal-variation at Huancayo to be small, the ratio with respect to solar diurnal-variation being about solar:lunar = 15:1- an order normal for most observatories—and much less than that obtained from data at the Batavia Observatory in approximately the same latitude as Huancayo, the ratio there being solar:lunar = 3.8:1. This appears to be a sig-

nificant result, further discussions and conclusions regarding which must await reductions for the other seasons, and especially reductions for horizontal intensity.

The analysis of the declination-observations of the *Galilee* and *Carnegie* in the Pacific 1905-29, according to Fisk's method for determining the secular variation, was continued. The results of this work for the first time yield values of secular variation in declination over the entire Pacific adjusted by the method of least squares.

A preliminary discussion of the latest secular-change values in the Caribbean Area and South America disclosed the need for closer grouping of repeat-stations in the region of focal centers of isopors. There was found to be an almost complete disappearance of any area of positive change in both horizontal and total intensity and a marked increase in the negative rate of change in total intensity in the extreme southern part of the Continent. The possibilities of a relation between subcrustal convection-currents and magnetic secular-variation, and also that the magnetic secular-variation may be due to a change in the state of the magnetic material in the Earth's crust due to a rising or falling of isotherms in the lower part of the crust, were also investigated.

Investigations of instrumental improvement for work at sea were continued through analyses of experiments performed with a standard liquid-compass in the automatic swing. The analysis together with a study of original declination-observations made on the *Carnegie*, and an examination of the records of rolling and pitching, suggest improvements in the methods of observing with any compass at sea for accurate declination.

Terrestrial Electricity

The reductions of the atmospheric-electric data obtained at College, Alaska, were continued, and furnish interesting information regarding the electrical conditions in polar regions. The continuous registration of the electrical elements of the atmosphere at Tucson, was continued under the cooperative arrangement with the United States Coast and Geodetic Survey.

Studies were made of the various types of ions in the atmosphere with a view of gaining a better record of the balance maintained between them and of arriving at a more satisfactory quantitative theory of the process. Investigations relating to the ionization near the ground during thunder-storms and to the sources of the nuclei, particularly in connection with occupied rooms were made. A study of electrical convection in the atmosphere, which plays so important a rôle in the development of the electrical state of the thunder-storm received consideration. Attention was also given to questions bearing on atmospheric-electric data to be published and to the development of apparatus for recording air-conductivity during flights in the stratosphere.

A more systematic study of the earth-current records from the Watheroo, Huancayo, and Tucson observatories have revealed definite observational evidence of an interesting new aspect of the system of electric currents circulating in the Earth's crust. There is not found, however, at Tucson that persistence of a single type of diurnal variation throughout the year which has been observed at Watheroo and Ebro,

and also (though of a distinctly different type) at the equatorial station at Huancayo. The changes which occur are most readily appreciated when the diurnal-variation data are given in hodographs, the form of which changes markedly from month to month but repeats itself remarkably in the same months of different years. There is thus presented a promising basis for study, in conjunction with the corresponding magnetic records, to determine the relationship between the two phenomena.

A comparison of the earth-current and auroral records at College shows considerable agreement between aurorae and disturbances in the earth-current records. Effect associated with brilliant isolated auroral displays at College are readily detected in the earth-current records at Tucson and in exceptional cases in those obtained as far south as Huancayo, Peru.

IONOSPHERE-INVESTIGATIONS

A considerable contribution to our knowledge of the structure of the upper atmosphere in equatorial regions was made through the ionospheric work at the Hunacayo Observatory. These experiments show that there are three sharply defined increases of ionizations of "layers" ordinarily apparent in the daytime with near-normal incidence of the Sun's rays, having virtual heights of about 100, 180, and 300 km, corresponding to the E-, F_1-, and F_2-layers of the temperate zones. The F_1- and F_2-layers are found to separate from a single F-layer which exists at night. Studies of variation of maximum ionization, double refraction, etc., are in progress. Because of the newness of the problem several methods of analysis are under consideration and test and no decision concerning any method is believed desirable at this time. Much time has been devoted to the development of instruments for this work. Effort has been directed toward the modification of the existing equipment to take advantage of this technique. The first step has been to provide equipment for automatic single-frequency and manual multi-frequency registration. This design is completed and construction is well advanced. Both the Huancayo and Watheroo observatories will be provided for upon completion of the equipment. The final step will be to modify the transmitter for automatic multi-frequency transmission. This involves a reduction of the power-input consistent with economical operation at isolated localities but without sacrifice of output.

Attention has been given in particular to the resolution of the recorded traces given by the new equipment so that the greatest detail is available. Definite advances have been made in this direction.

NUCLEAR-PHYSICS RESEARCH

The extension to the Experiment Building to house the 2-meter electro-static generator was completed in July 1933. Tests showed that the true maximum positive potential attainable on the outer shell of the generator was 1200 kilovolts.

From the experimental work thus far conducted, it was found, working with pure gases, that heavy hydrogen itself occluded on the solid targets was a contamination responsible for many of the disintegration-effects observed using deutons. The expectation of obtaining neutron-

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intensities with the new equipment far in excess of any neutron-intensities possible with radioactive sources was realized. Using approximately 0.5 microampere of deutons at 1200 kilovolts, bombarding a Be-target, a source emitting more than 500,000,000 neutrons per second was demonstrated—10 to 100 times as great as the strongest radioactive source so far reported.

The evidently continuous distribution of energies of the disintegration-proton observed at the Department from the deuton-deuton reaction even in the "thin-target" gas-bombardment experiments, is an anomaly which is receiving attention. Evidence for the existence of stable hydrogen atoms of mass three was found. The method depends on the simple fact that for the same initial velocity, the energy of a mass-three hydrogen-nucleus will be three times that of a proton, and since it bears the same charge of unity the rate of loss of energy per centimeter will be nearly identical and hence its range in air will be three times as great. The magnetic analysis of the constant-voltage ion-beam acts as a velocity-filter, bringing together at the mass-three spot proton-deuton-molecules and mass-three nuclei of the same velocity. Examination of the ranges of particles present in the mass-three spot showed a faint group having the long range predicted for H^3. Quantitative confirmation of this new isotope was shortly afterwards reported by investigators at Princeton University, using an entirely different method.

MAGNETIC SURVEY

The study of secular variation in the Earth's magnetic elements continued the chief concern of the Section of Land Magnetic Survey. Continued adverse economic conditions permitted only a limited amount of field-work by Department observers, and through cooperative work with other organizations, in South Africa, British East Africa, and China. The Department's expedition in the southern and eastern part of South America was brought to a conclusion early in the report-year. Arrangements with the Byrd Antarctic Expedition II were concluded assuring the occupation of a number of stations in Little America.

OBSERVATORY-WORK

The magnetic-atmospheric-electric, earth-current, and meteorological programs at the Watheroo and Huancayo observatories, and the cooperative work in atmospheric electricity with the Apia Observatory (Department of Scientific and Industrial Research of New Zealand), and in atmospheric electricity and earth-currents at the Tucson Observatory of the United States Coast and Geodetic Survey were maintained.

At the Watheroo Magnetic Observatory in addition to the Eschenhagen magnetograph the la Cour rapid-running magnetograph was in continuous operation, scale-value observations by the electrical method being made. The Crichton Mitchell vertical-intensity electrograph was in continuous operation and quite satisfactory records are being obtained. Since October 1933 observations of sunspots, flocculi, and prominences were made with the Hale spectrohelioscope—over 100 sketches were made. Upon request, information regarding housing and mounting of the spectrohelioscope was supplied the director of the Mount Stromlo Solar Observatory.

At the Huancayo Magnetic Observatory observations with the spectrohelioscope were hampered by the persistent bad weather and the condition of the mirrors and rotating prisms. The seismological station, including the two Wenner horizontal-component seismometers and the Benioff vertical seismometer, was operated during the entire year. The ionosphere-apparatus was continued in operation, the program for the International Polar Year being completed during August. Thereafter, until early in 1934, a restricted program was followed, but after February 1934 the full cooperative program with the National Bureau of Standards of the United States was begun. This program has been productive of important results which were reported upon in a paper by Berkner and Wells entitled "Ionosphere-measurements at low latitudes." The la Cour magnetograph installed for the Polar-Year work, was continued in operation after the end of that period and proved of value not only in recording on a very open time-scale but also in cases of failure of the Eschenhagen instrument. Continuous registrations were made of the ionization due to the cosmic radiation; although reductions of these data have not yet been made, a preliminary survey indicates that the "Stösse" show a diurnal variation.

The participation of the Department in the work of the Polar-Year stations at College-Fairbanks and Point Barrow was continued, and the reduction of the earth-current and atmospheric-electric data is nearly completed. The cooperation with the International Polar-Year stations at Capetown, Chesterfield Inlet, and Magallanes, was maintained.

The manuscript of the magnetic results at the Watheroo Magnetic Observatory during 1919 to 1932, is ready for publication. Corresponding manuscript for data obtained at the Huancayo Magnetic Observatory was completed for the years 1922, 1923, and 1927 to 1932, and compilations for the years 1924 to 1926 are progressing rapidly.

The atmospheric-electric and earth-current data obtained (the former during September 1932 to August 1933 and the latter during September 1932 to March 1934) at the International Polar-Year station College-Fairbanks in Alaska are being compiled. The compilations of the magnetic results obtained at Point Barrow will be started soon when personnel is available.

The discussions of completed compilations of magnetic data obtained in cooperation with the Macmillan Baffin Island and North Greenland expeditions of 1921-22 and 1923-24, respectively, and of the first Byrd Antarctic Expedition of 1928-30 were prepared. It was found that, as a result of the experience acquired in the preparation of the report on the first Byrd Antarctic Expedition, improvement could be made in the reports of the Macmillan expeditions. These final revisions are under way.

OCEANOGRAPHIC REDUCTIONS

The manuscripts and numerous graphs and charts on the physical and chemical results obtained during the last cruise of the *Carnegie* and the discussion of meteorological results are now completed and ready for final assembly except for the discussion relating to bottom-samples. The extended report on the last, being prepared at the Scripps Institution of Oceanography, is nearly finished. The various reports on the biological results are being rapidly completed.

Miscellaneous

As in the past the policy of the Department of cooperating with other investigators and organizations interested in similar work was maintained and extended.

The member of staff who was largely responsible for the successful magnetic survey of the oceans, William J. Peters, retired from active duty June 30, 1934. His has been a long and productive service in the Department since January 1, 1906. He devised many instrumental improvements and methods used at sea and invented the marine collimating-compass. More recently he concentrated on the investigation of tilting deviations in magnetic measurements at sea and of magnetic storms. Fortunately his experienced and friendly counsel will continue available to his colleagues on the staff.

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ARTHUR SCHUSTER, 1851-1934

By S. Chapman

On Sunday, October 14, 1934, at the age of 83, Sir Arthur Schuster died at his home, Yeldall, near Twyford, Berkshire, England, after a long and distressing illness. The science of terrestrial magnetism and electricity thus loses one who made outstanding contributions to its progress.

Arthur Schuster was born[1] at Frankfort-on-Main on September 12, 1851, of a Jewish family which, as early as the middle of the eighteenth century, had established a business in cotton goods in England. Till the age of sixteen he lived in Frankfort, where his father was a banker; he then studied French for two years at Geneva. In 1870 he joined his family in Manchester, whither they had emigrated in 1869, and entered his father's business. In the evenings he attended classes at the Owens College (afterwards the University) in that town, and within a year persuaded his father to let him leave the business to follow a scientific career. For a year he studied physics under Balfour Stewart (professor of physics at Manchester, 1870-87), and then studied spectrum analysis for two years under Kirchhoff at Heidelberg, where he obtained the Ph.D. in 1873. Returning to Manchester, he became an unpaid assistant to Balfour Stewart for a year, then studied at Göttingen under W. Weber and at Berlin under Helmholtz; led a British eclipse expedition to Siam (at the age of twenty-four); spent another year as honorary assistant at Manchester; worked for nearly two years in the Cavendish Laboratory, Cambridge, first under Clerk Maxwell and later under Rayleigh; and in 1878 accompanied another eclipse expedition, to Colorado. This unusually long and varied training, made possible by the support of a wealthy and enlightened parent, enhanced the fruitfulness of his great natural gifts—not only in his capacity as an individual scientific worker, but also, especially in his later years, as a leader in international scientific organisations, work for which he was peculiarly well fitted by his administrative ability and his knowledge of languages.

In 1881 he became professor of applied mathematics at Manchester, and in 1888 succeeded Balfour Stewart as professor of physics. There he designed new physical laboratories, in which much distinguished experimental work has been done, by himself and his pupils, and by or under his successors in the chair, Rutherford and W. L. Bragg. He also took an important part in the development of the university. He retired from his professorship in 1907, but not from active work; he was secretary of the Royal Society (of which he became a Fellow at the early age of twenty-eight) from 1912 to 1919, and of the International Research Council from 1919 to 1928. It would take too long to recount the many other important offices that he filled, or the scientific honours that were bestowed on him; but the Royal Society awarded him a Royal and a Rumford medal, and, in 1931, its highest honour, the Copley medal.

[1] Most of the biographical details here given are taken from a notice in *Nature*, 134, 595-597 (1934).

Personally he was retiring and reserved in manner, despite his force of character and the prominence of his position. To those with whom by circumstance or common interests he came into close contact, he was a loyal friend and helper—and few professors took a more active interest in their students. He was a notably clear thinker, and this was reflected in his speech and writing; his book on optics is a model of lucidity in exposition. His attitude of mind was liberal and enlightened, and his generosity of spirit was shown not only in his personal and scientific relationships, but also by many valuable benefactions for science.

His scientific interests and range of work were wide. Only his work on terrestrial magnetism can be described here, but this was greatly enriched by his knowledge of other fields apparently only slightly connected with it. Thus his interest in optics helped him in his pioneering work on the periodogram, which Dr. Bartels describes in a separate notice, and which has important bearings on solar physics, magnetism, and meteorology. Again, his work on spectrum analysis, leading on to the study of electric discharges in gases, bore closely on problems of magnetic variation. Besides being a gifted experimenter, he was an accomplished mathematician, and wrote many mathematical papers on general electrical theory as well as on terrestrial magnetism. Seismology, meteorology, and solar physics were other subjects that keenly interested him.

In terrestrial magnetism his work was of high value. In 1889[2] he applied the method of spherical harmonic analysis, as Gauss had suggested, to the field of the daily magnetic variation. He thus showed conclusively that the field mainly originates above the Earth. There is also, however, a part of internal origin, and with the help of his colleague Professor H. Lamb, he showed that this could reasonably be attributed to currents induced in the Earth by the primary varying field. He found that the internal part of the field indicated a greater conductivity of the Earth at deeper levels than near the surface

In that paper he expressed confidence in the theory, originated by his old teacher and colleague, Balfour Stewart, that the daily magnetic variation is due to electric currents in the upper atmosphere, induced by periodic convection of the air across the Earth's lines of magnetic force. His own work, on electrical conductivity of gases, had already helped to remove a difficulty then felt, as to the possibility of air being able to convey the necessary currents. In 1907[3] he returned to the subject, and elaborated this "dynamo" theory mathematically. He assumed a periodic system of air-currents, associated with the daily barometric variation, and calculated their effect, assuming a distribution of electrical conductivity in the upper air, depending on the Sun's zenith-distance. He attributed the conductivity to ionization by solar ultra-violet radiation, and was able to make an estimate of the total conductivity of the current-bearing layer. He urged the importance of an extended study of the lunar daily magnetic variations as a further test of the theory[1]. Since then radio methods have added greatly to our knowledge of the ionization in the upper air, while at the same time the important influence of the

[2]Phil. Trans. R. Soc., A, **180**, 467 (1889).
[3]Phil. Trans. R. Soc., A, **208**, 163 (1908).
[1]It was his influence that led me to take up this work, and for some time he kindly lent me the assistance of his private secretary in the necessary computations.

Earth's magnetic field on the electric conductivity of the air has become recognized. It is now doubtful whether the dynamo theory is valid for the solar daily magnetic variation, but it probably applies to the lunar daily magnetic variation. In connection with this Schuster's theoretical work retains its importance, while his separation of the internal and external parts of the daily-variation field remains a classic of terrestrial magnetism.

In 1896 he published an interesting paper, in the first number of this JOURNAL[5], on the rotation of a magnetized body within a conducting medium, and discussed the possible bearing of the theory on the secular magnetic variation. In this paper also he signalized his intention of making a spherical harmonic analysis of the Earth's permanent field, having as its object the calculation of the two leading harmonics with special accuracy. He seems never to have carried out this intention, though it led him to consider the best method of spherical harmonic analysis, on which he wrote a note for the Bristol Conference on Terrestrial Magnetism, of 1898, and a long and detailed paper in 1902[6].

It was at Bristol in 1898 that he made the personal acquaintance of Adolf Schmidt, who shared in full measure his wide understanding of the problems of terrestrial magnetism, his physical insight into them, and his power of fruitfully applying mathematics to their elucidation. Schuster, whose scientific work was wider in range than that of Schmidt, had however a less detailed knowledge of terrestrial magnetism; their common interest in the subject included, besides theoretical questions, instrumental methods and methods of reduction and discussion. Schuster strongly advocated[7] the adoption of electrical methods of measuring the magnetic elements, and his influence, advice, and financial support, added to the experimental skill of F. E. Smith (now Sir Frank Smith), resulted in the construction of the Schuster-Smith magnetometer; this is now the standard instrument for the absolute measurement of horizontal magnetic force at Abinger, and has served to calibrate a number of smaller instruments of the same type, forming secondary standards for use at other observatories. The late W. D. Dye constructed a similar standard instrument for the vertical force.

For many years Schuster influenced the work of the various British magnetic observatories through his membership of the Board of Visitors of the Royal Observatory, Greenwich, of the Meteorological Committee, and of the Gassiot Committee of the Royal Society. His advice to these bodies was greatly and justly valued. Perhaps one of his few misjudgments was that which led to the publication for certain observatories of hourly values of north and east force instead of for horizontal force and declination; this plan is no longer followed at British observatories. His advocacy of it seems to have been due to an exaggerated sense of the burden of computation involved in the discussion of magnetic data.

In the Philosophical Magazine for October 1898 he examined the direct magnetic effect at the Earth of a possible magnetization of the Sun, taking account of the Sun's rotation and the obliquity of its axis to the eclipse. His object was to show the probable unimportance of any

[5]Terr. Mag., **1**, 1 (1896).
[6]Phil. Trans. R. Soc., A, **200**, 181 (1902).
[7]*Cf*, this JOURNAL, **19**, 19 (1914).

variation of the Earth's field with the period of the Sun's synodic revolution. The now known magnetic moment (and also radial limitation) of the Sun's magnetic field, as determined by Hale and his colleagues at Mount Wilson, shows that any such direct effect must be quite negligible. It was not until 1904 that the nature of the often-suspected periodicity agreeing in duration with the Sun's synodical revolution rendered clear by Maunder, who revealed it as a recurrence-tendency, not a true periodicity. Maunder's work was discussed by Schuster in 1905[8] in a rather adverse spirit, and his paper included some too heavy-handed strictures on Maunder's discussion of the theoretical significance of the recurrence-tendency. Later work by Maunder himself, by Chree, Stagg, Bartels, and others has established the recurrence-tendency as one of the outstanding characteristics of the magnetic variations.

In 1900[9] he discussed the precession of a system of electric currents in a rotating body; and showed that if the Earth's magnetism is due to internal electric currents, a precession of the system would occur, but much more slowly than the rate at which at that time the Earth's magnetic axis was supposed to be precessing round the geophysical axis.

In 1911 Schuster discussed the still-vexed question of the origin of magnetic storms[10], and gave a useful criticism of theories that had been advanced, according to which such storms manifest the direct magnetic field of streams of electrified particles from the Sun; he argued from considerations both of energy, and of electrostatic repulsion, that such theories were untenable.

In the following year he took as his subject for a presidential address to the Physical Society "A critical examination of the possible causes of terrestrial magnetism"[11]. Though the origin of the Earth's field remains deeply mysterious, Schuster's discussion of the subject was acute and its value remains. In this paper he referred to experiments that he had initiated and which for several years were carried out at Manchester to test the influence of pressure on the critical temperature for the magnetization of iron; such experiments were only recently carried to a successful conclusion, in the Geophysical Laboratory of the Carnegie Institution of Washington. He was also experimenting at the same time on the magnetization of bodies by rotation, in which field S. J. Barnett[12] was the first to achieve successful results.

Schuster's last paper[13] in terrestrial magnetism was published in 1926, and was concerned with the very fundamental and still unsettled question as to the magnitude of the earth-air current suggested by the non-zero line-integrals of magnetic force round closed contours on the Earth's surface: and therefore also with the possible existence of a non-potential part of the Earth's field. The paper bore the too modest title of "A review of Mr. George W. Walker's magnetic survey" (of the British Isles, of 1915). Actually the paper was based on extensive computations in which the whole of Walker's material was recalculated applying the method of least squares. His principal object in undertaking this labor

[8]Mon. Not. R. Astr. Soc., **65**, 186 (1905).
[9]Phil. Mag., **1**, 314 (1901).
[10]Proc. R. Soc., A, **85**, 44 (1911).
[11]Proc. Phys. Soc., **24**, 121 (1912).
[12]Phys. Rev., **6**, 239 (1915).
[13]Proc. R. Soc. A, **111**, 68 (1926).

was to find an area in which the magnetic forces vary with sufficient regularity to give a decisive test of the earth-air current, but in this he was disappointed. Though his results were in fair agreement with those of A. Schmidt and L. A. Bauer, he did not regard the evidence as conclusive, and therefore he devised and proposed a plan of observation confined to a small area of tested regularity of magnetic distribution. His plan has unfortunately not yet been put into operation.

Theoretical progress in terrestrial magnetism is halting and uncertain; sometimes positions that seem to have been gained (as in the case of the dynamo-theory of the daily magnetic variation) have later to be abandoned; compared with the triumphal advance in other parts of physics, terrestrial magnetism seems almost at a standstill. Yet if we look back to the state of knowledge, both as regards the facts and theories of terrestrial magnetism, at the beginning of Schuster's scientific career, and compare it with the present state, many important advances are seen to have been made; they are partly positive, and partly consist in the clearing away of false ideas. Balfour Stewart, Schuster, Maunder, Schmidt, Bauer, Birkeland, Chree, and Störmer, are among the leaders in this advance, and Schuster's part, both constructive and critical, will always rank high in the annals of terrestrial magnetism.

ARTHUR SCHUSTER'S WORK ON PERIODICITIES

By J. Bartels

Geophysics and cosmical physics owe to Sir Arthur Schuster the fundamental discovery that research on periodicities, cycles, and related phenomena requires, besides purely analytical calculations, such as harmonic analysis or Fourier series, essentially statistical considerations based on the theory of probability. His first paper on this subject, which appeared in this JOURNAL, gives the outline of a theory which was later applied to various meteorological, terrestrial-magnetic, and cosmical periodicities. These classical papers, the study of which should be part of the training of every geophysicist, are: (1) On the investigation of hidden periodicities with application to a supposed 26-day period of meteorological phenomena (Terr. Mag., **3**, 13-41, 1898); (2) The periodogram of magnetic declination as obtained from the records of the Greenwich Observatory during the years 1871-1895 (Cambridge, Trans. Phil. Soc., **18**, 107-135, 1899); (3) On the spectrum of an irregular disturbance (Phil. Mag., **5**, 344-346, 1903); (4) The periodogram and its optical analogy (Proc. R. Soc., A, **77**, 136-140, 1906); (5) On the periodicity of sunspots (Phil. Trans. R. Soc., A, **206**, 69-100, 1906); and (6) On the periodicity of sunspots (Proc. R. Soc., A, **85**, 50-53, 1911).

Though over 30 years have passed since Schuster's first paper was published, it cannot be said that his ideas belong to the standard knowledge of every worker in this field. Various reasons for this unsatisfactory state can be indicated. The first lies perhaps in the condensed form in which Schuster published his theory, making the access difficult to many workers who had to look for an explanation of the periodogram from second and third hands. This has led to erroneous applications of his method which he himself would have rejected, but which were dangerous

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because they claimed to be based on his theory; this fate of misconception is shared by periodogram-analysis with the theory of correlation. Secondly, Schuster himself seems to have had no particular preference for the heavy arithmetic work necessarily involved in the practical applications of his theory, so that he did not guide and help his followers in this respect. And finally, this theory in its original form fits only a special kind of periodicities which could be termed persistent, and which, beyond the obvious cases of solar and lunar diurnal or annual variation, are rather rare.

As to an account and an extension of Schuster's theory, as well as a review of the literature, the reader may be referred to a paper on "Random fluctuations, persistence, and quasi-persistence in geophysical and cosmical periodicities," to appear in the March 1935 number of this JOURNAL.

OLE KROGNESS AND HIS WORK

By L. Vegard

The premature death of Professor O. Krogness will be greatly regretted, not only by his family and numerous friends, but also by those who have been engaged in the study of solar and terrestrial relationships during the last twenty years.

Born at Trondheim in 1886, he had reached only the age of 48. His early death is the more deplorable, as most of his activity had been devoted to the development of new institutions for research, to new observational stations, and to the collection of observational material.

When in 1928 he moved from Tromsø to take up a professorship in terrestrial magnetism and cosmical physics at Bergen, he hoped to be able to gather the fruits of his earlier activity and to work out and publish the results of extensive series of observations obtained in various localities, especially in Northern Norway during previous years. His death, however, prevented the realization of his plans. Under these circumstances we would receive a false impression of the scientific importance of his work and activity if we gave chief consideration to his published papers.

In 1906 he was engaged as an assistant to the late Professor Kr. Birkeland. The writer had then for some time been attached to Birkeland's staff and he worked with Krogness for several years on the treatment of the data from Birkeland's expeditions to the polar regions during the year 1902-03, the results of which appeared in the well-known work of Birkeland on "The Aurora Polaris Expedition 1902-03."

This period of collaboration with Birkeland had far-reaching consequences for our later careers in life. It gave both of us a deep interest in cosmic-terrestrial phenomena and led to a friendship and cooperation in scientific research which lasted until Krogness' death. On the initiative of Birkeland an observatory was built on the top of Haldde Mountain near the Altenfjord in Finmark, and at its start in 1912 Krogness became its first director.

During the winter 1912-13 the writer maintained a station at Bossekop for the study of various auroral problems, and was able to cooperate with Krogness at the Haldde Observatory obtaining simultaneous auroral pictures for height-measurements. Our cooperation in auroral work was continued for several years and resulted in a number of joint publications of which we may call attention to the following: Höhenbestimmungen des Nordlichts an dem Halddeobservatorium in Okt. 1912 bis Jan. 1913" (Vid. selsk. skr. I, No. 11, 1914) and "The Position in Space of the Aurora Polaris" (Geofys. Pub., **1**, No. 1, 1920).

Birkeland on many occasions advocated the idea that relationships might be found between meteorological phenomena and solar activity which manifest themselves as aurorae, magnetic storms, and allied phenomena. Accordingly, the study of meteorological phenomena occupied an important part in the programme of the Haldde Observatory.

On account of the practical importance of weather forecasting, the weather service had to be reorganized for Northern Norway, and although Krogness could entrust a considerable part of the work of this meteorological organization to Dr. O. Devik, the meteorological problems also demanded a great deal of attention from Director Krogness himself.

The position of the Haldde Observatory being in many respects

most inconvenient, Krogness and Devik obtained funds for building a new Geophysical Institute at Tromsφ, and in 1918 Krogness became director of the new Institute.

The name Geophysical Institute was chosen to indicate that not merely meteorology but also magnetic and auroral work was to be included in the programme of the Tromsφ Institute; but here, even more than at Haldde, most of the activity was devoted to meteorology and weather service. In fact Krogness became the Director of the Meteorological Office of Northern Norway, and in that capacity he had also to take a prominent part in the erection of a number of meteorological stations in the arctic for example at Greenland, at Baeren Island, in Spitzbergen, on Jan Mayen and his great experience in the arctic matters was in great demand by a number of arctic expeditions.

In spite of the heavy duties which Meteorology had laid on the Haldde Observatory and even more on the Tromsφ Institute, observations of aurora and terrestrial magnetism were continually kept up. Records of three magnetic elements were undertaken at the Haldde Observatory from the beginning and they were continued until 1926 by H. Kφhler some years after Krogness left for Tromsφ; moreover many auroral observations were made by Krogness and his collaborators both at the Haldde Observatory and at Tromsφ.

It will be understood that his administrative duties made it difficult for him to pursue his interest in cosmical physics and to utilize the extensive observational material relating to aurora and terrestrial magnetism. Although he made no systematic publication of the material collected in this field, he utilized it for the study of special problems and phenomena of particular interest which he had occasionally observed.

Following the idea of Birkeland, he gave much attention and labor to the problem of finding a connection between meteorological phenomena and solar activity; he also studied the relationship between aurora and magnetic disturbances and described a number of interesting cases of auroral displays.

Unfortunately he never found time to publish a more complete account of these extensive and very laborious investigations, and has left only summaries in short papers, some of which were read at geophysical congresses, and at meetings of the Norwegian Academy.

The best summary of his work relating to the problems referred to will be found in a series of articles which appeared in the Norwegian journal "Naturen" March to April 1917 and in a paper published at Tromsφ in 1928 entitled "Short Report of Various Researches Regarding Aurora Borealis and Allied Phenomena."

These summaries bear witness to extensive studies and an intimate knowledge of the phenomena acquired during many years of personal experience in the arctic regions. As he merely gives fairly short statements of the results and of the conceptions he has formed regarding the various relationships treated, we are in many cases unable to form a definite opinion as to whether or to what extent his results hold good; but at any rate his summaries deal with a number of important problems and contain most suggestive ideas, which will no doubt be most valuable to future workers in this field. From statistical studies of the variation of meteorological elements and magnetic storminess (which he considers to be the best exponent of solar activity), he found that both phenomena,

[Plate 5]

Ole Krogness

apart from daily and annual variations, also show the following periods: 14 days, 27 days, 2 years, 11 years, 100 years, and he discussed the possibility of one long period of about 1000 years.

By coordinating the perturbing forces operating during auroral displays, he found evidence for the view that a great part of the perturbing effect is caused by electric currents flowing along the auroral arcs. The rapidly-moving forms, however, should have only a small magnetic effect. These results, however, do not quite agree with those of other observers. Thus the writer from his observations at Bossekop, 1912-13, came to the conclusion that the aurora probably had a comparatively small direct magnetic effect, and that the magnetic storms were mainly due to current-systems not connected with auroral luminescence, and probably situated above the auroral region. The question regarding the correlation between aurorae and magnetic disturbances, however, is by no means settled, and the view expressed by Krogness calls for earnest consideration. He further studied the periods of pulsating aurorae and coordinated them with typical magnetic changes but found no simple correlations.

Serious consideration should be given to his discussion of the diffuse luminous areas, which he calls auroral clouds. Following the suggestion of the writer that these clouds might be due to an afterglow in the atmosphere, which follows intense auroral displays, he regarded them as ionized clouds, floating in the atmosphere and thus affording us means of determining the "wind" motion in the auroral region. He found velocities of 50 to some hundred meters per second in good agreement with results obtained from the observations of the "luminous night-clouds." He also pointed out the remarkable fact, that the diffuse auroral clouds seem to be particularly effective as absorbers of radio waves, while ordinary aurorae show little or no effect.

The cooperation between meteorology and cosmical physics had not been satisfactory, hence in 1927 a separate organization called The Norwegian Institute of Cosmical Physics was formed, the object of which was to superintend and conduct researches on aurorae, terrestrial magnetism, etc. An auroral observatory was built at Tromsø from funds given by the Rockefeller Foundation, and a Magnetic Bureau was erected at Bergen. In connection with this organization Krogness obtained a professorship at Bergen, where his principal duty was to conduct the work at the Magnetic Bureau.

As a member of the Executive Committee of the Norwegian Institute of Cosmical Physics he greatly assisted in the organization of the Auroral Observatory, Tromsø, especially in planning the magnetic work.

With the assistance of Mr. Wasserfall he began a systematic discussion of the magnetic records from the Haldde Observatory, covering the period from 1913 to 1926, and from the station Dombaas in Southern Norway from 1916 to date. A considerable part of this rather laborious work had been completed but he did not live to see the results published.

Krogness was a broad-minded man, whose talents and interests covered many subjects. He was a gifted mathematician. Had he not devoted himself to science, he might have become a prominent musician. He was a charming man, the best of friends, and one who was always ready to help where and when help was wanted.

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LETTERS TO EDITOR

PROVISIONAL SUNSPOT-NUMBERS FOR SEPTEMBER TO NOVEMBER, 1934

(Dependent alone on observations at Zürich Observatory and its station at Arosa)

Day	Sep.	Oct.	Nov.	Day	Sep.	Oct.	Nov.
1	0	15	13	17	8	8	0
2	0	0	14	18	0	8	7
3	7	0	16	19	0	14	. .
4	0	8?	14	20	0	0	0
5	0	0	12	21	0	0	0
6	0	0	. .	22	0	7	0
7	0	0	10	23	7	8	0
8	0	0	8	24	0	0	0
9	0	0	10	25	0	7 ʰ	7
10	. .	0	7	26	0	7	$M11^a$
11	0	7	7	27	0	7	14
12	7	8	7	28	9	7	23
13	7	8	0	29	14	10	$W36^c$
14	8	8	0	30	21	16	32
15	$W16^a$	. .	0	31		8	
16	9	. .	0	Means	3.9	5.6	8.9
				No. days	29	29	28

Mean for quarter July to September, 1934, 7.3 (89 days)

[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group through the central meridian.
[c]New formation of a small center of activity: E, on the eastern part of the Sun's disc; W, on the western part; M, in the central zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

Zürich, Switzerland   W. Brunner

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, JULY, AUGUST, AND SEPTEMBER, 1934

Greenwich mean time						Range Hor. int.
Beginning			Ending			
1934	h	m	d	h	m	γ
July 3	10	31*	4	4	. .	128
July 30	3	19	31	6	. .	120
Sept. 24	4	. .	25	23	. .	140

*A sudden commencement but the time is uncertain because the timing clock was stopped.

No sunspots were visible and no exceptional activity was recorded by the spectroheliograph on the days of the July storms, or on the days immediately preceding them. No spectroheliograms were made on September 22, 23, and 24. A disturbed region which may have been active on the preceding days was recorded by the spectroheliograph on September 25. No spots were seen in this disturbed area until September 28, the date on which it crossed the central meridian.

	July 1934								August 1934								September 1934							
Day	K_2		HaB		HaD		No. groups	Mag'c char.	K_2		HaB		HaD		No. groups	Mag'c char.	K_2		HaB		HaD		No. groups	Mag'c char.
	A	B	A	B	A	B			A	B	A	B	A	B			A	B	A	B	A	B		
Mean	0.7	0.3	0.9	0.4	0.8	0.2	1.1	0.2	0.6	0.3	0.7	0.2	0.6	0.2	0.8	0.3	0.7	0.5	0.7	0.4	0.8	0.1	0.6	0.3

NOTE.—For an explanation of these tables see this JOURNAL, **35**, 47-49 (1930).

? Indicates an uncertain value which should be given low weight.

a ., ', 'Passage of an average-sized group through the central meridian within 5°, 25°, 35° of the center of the disc, respectively.

d, 'Passage of a small group through the central meridian within 5°, 40° of the center of the disc, respectively.

Carnegie Institution of Washington, Mount Wilson Observatory.
Pasadena, California

SETH B. NICHOLSON
ELIZABETH E. STERNBERG

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1]
JULY TO SEPTEMBER, 1934

The data for terrestrial magnetism, sunspots, solar constant, and auroræ are the same as given in previous tables.

Kennelly-Heaviside Layer heights, Washington, D. C., July to September, 1934
(Nearest hour, Greenwich mean time, of all observations is 17)

Date	Frequency	Height	Date	Frequency	Height	Date	Frequency	Height
1934	kc/sec	km	1934	kc/sec	km	1934	kc/sec	km
Jul. 4	2,500	120	Aug. 1	5,000	110	Sep. 5	3,800	120
" "	3,000	130	" "	6,000	110	" "	4,000"	130, 270
" "	3,500	140	" "	7,000	110	" "	4,400	410
" "	3,800	*	" "	8,000	110	" "	5,000	300
" "	4,000	320	" "	9,000	110	" "	5,200	340, 590
" "	4,120	660	" "	9,400	120	" "	5,800	400
" "	4,400	440	" 8	2,600	120	" "	6,000	520
" "	5,000	130	" "	3,400	120	" "	6,100	*
" "	6,000	110	" "	3,500	140	" 12	2,500	120
" "	7,000	120	" "	3,540	*	" "	3,200	140
" "	7,200	*	" "	3,550	200	" "	3,250	*
" 11	2,800	120	" "	3,850	230, 420	" "	3,300	200
" "	3,500	110	" "	3,900	230	" "	3,400	170, 230
" "	3,900	120, 320	" "	3,970	230, 530	" "	3,750	200
" "	4,200	460	" "	4,600	460	" "	4,200	*
" "	4,400	120, 440	" "	5,000	550	" "	4,350	410
" "	5,000	110, 380	" "	5,300	530	" "	4,600	300
" "	5,500	140	" "	5,800	500	" "	5,200	320, 410
" "	6,000	140	" "	5,900	*	" "	5,500	360, 440
" "	6,800	120	" 15	3,000	110	" "	6,100	380
" "	7,000	*	" "	3,450	130, 190	" "	6,200	*
" 18	2,600	120	" "	3,620	180	" 19	2,500	120
" "	3,600	110	" "	3,640	*	" "	3,000	140
" "	3,780	230	" "	3,650	230	" "	3,130	*
" "	3,900	170	" "	3,750	210	" "	3,150	240
" "	4,100	210	" "	4,000	240	" "	3,400	200
" "	4,350	220, 590	" "	4,100	*	" "	4,250	420
" "	5,000	180, 360	" "	5,100	460	" "	4,700	250, 330
" "	5,500	150, 410	" "	5,500	430	" "	4,900	270, 330
" "	6,000	160	" "	5,900	440	" "	5,100	340, 400
" "	6,500	180	" "	6,000	*	" "	5,300	360, 550
" "	6,800	160	" 22	2,500	120	" "	5,500	360
" "	7,000	*	" "	2,930	140	" "	5,900	410
" 25	2,500	120	" "	3,350	120, 260	" "	6,000	*
" "	3,000	110	" "	3,600	120, 230	" 26	2,500	120
" "	3,170	140	" "	4,130	710	" "	3,040	140, 250
" "	3,300	*	" "	4,500	400	" "	3,110	220
" "	3,400	220	" "	4,800	450	" "	3,130	*
" "	3,550	190	" "	4,900	*	" "	3,150	280
" "	4,320	670	" 29	3,000	110	" "	3,400	200
" "	4,400	530	" "	4,000	120	" "	4,300	470
" "	4,500	420	" "	4,800	110, 250	" "	4,500	300
" "	4,600	640	" "	5,100	120, 640	" "	4,700	350
" "	4,700	*	" "	5,200	110	" "	5,100	380
" "	4,900	300	" "	6,100	120	" "	5,500	390, 560
" "	5,000	*	" "	7,100	110	" "	5,700	390
Aug. 1	2,500	120	" "	7,500	210	" "	6,000	380
" "	3,300	110	" "	7,700	*	" "	6,400	520
" "	4,400	120	Sep. 5	2,700	110	" "	6,500	*

* = No value obtained.

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The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Electricity, (2) the type featuring the day other than normal by the letters b, p, o, and i for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N = k \, (10g + s)$, where k for Mount Wilson is about 0.7.

Mount Wilson Observatory is now supplying corrections and additions to the sunspot-data which are broadcast in the *URSI*gram. So far as possible, these additional and corrected values will be used in this tabular summary and will be designated as such in footnotes to the Table.

Summary American URSI daily broadcasts

	July							**August**															
Date	Magnetism			Sunspot		Solar constant		Magnetism			Sunspot		Solar constant			Aurora							
	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.	Char.	Duration	Cloudiness	Form		Area covered	Av. Altitude
																		With-out rays	With rays		
			h m			cal				h m			cal			hrs					
1	0	b	3 20	0	0	. . . . .	. . .	1	0	1 00	0	0	1.957	f	. . .	. . .	. .	. .	.	.	. .
2	0	. .	. .	0	0	. . . . .	. . .	0	. . .	. .	0	0	. .	. .	. .	. . .	. .	.	.	.	. .
3	0	. .	10 30	0	0	1.956	f	1	. .	. .	0	0	1.943	u	. .	. .	. .	.	.	.	. . .
4	1	. . .	. .	0*	0*	1.954	f	1	. . .	. .	0	0	. .	. .	. . .	. .	. .	. . .	. . .		
5	1	. . .	. .	0	0	1.966	f	1	. . .	. .	0	0	. . . .	. . .	. . .	. . .	. .	. . .	. . .		
6	0	. . .	. .	1	1	1.955	f	0	. . .	. .	1*	1*	1.972	f	. . .	. . .	. .	. . .	. . .		
7	0	. . .	. .	1	1	1.959	s	0	. . .	. .	1	1	1.960	f	. . .	. . .	. .	. . .	. . .		
8	0	. . .	. .	1	1	1.958	s	0	. . .	. .	1	3	1.967	u	. . .	. . .	. .	. . .	. . .		
9	1	. . .	. .	2	3	1.967	u	0	. . .	. .	1	5	. . . .	. . .	. . .	. . .	. .				
10	0	. . .	. .	2	4	1.944	f	0	. . .	. .	1	1	1.968	u	. . .	. . .	. .				
11	0	. . .	. .	3^a	3^a	1.965	f	0	. . .	. .	1	1	1.944	u	. . .	. . .	. .	.	.		
12	0	. . .	. .	3^b	4^b	1.972	u	0	. . .	. .	2^g	4^g	1.948	s	. . .	. . .	. .	.	.	. . .	
13	0	. . .	. .	3^c	4^c	1.976	u	1	. . .	. .	2^h	9^h	. . . .	. . .	. . .	. . .	. .	.	.	. . .	
14	0	. . .	. .	3	3	1.955	f	0	. . .	. .	2^i	7^i	1.944	u	. . .	. . .	. .	.	. . .		
15	1	. . .	. .	2^b	2^b	1.966	f	0	. . .	. .	2^j	9^j	1.947	u	. . .	. . .	. .	.	. . .		
16	1	. . .	. .	2^b	2^b	. . . . .	. . .	0	. . .	. .	2^k	9^k	1.949	f	. . .	. . .	. .	.			
17	0	. . .	. .	2^b	2^b	. . . . .	. . .	0	. . .	. .	2^l	2^l	. . . .	. .	. . .	. . .	. .	.			
18	0	. . .	. ./	2^b	2^b	. . . . .	. . .	1	. . .	. .	3^*	5^*	. . . .	. .	. . .	. . .	. .	.			
19	0	. . .	. .	1^d	1^d	. . . . .	. . .	1	. . .	. .	*	*	. . . .	. .	. . .	. . .	. .				
20	0	. . .	. .	1^d	1^d	1.942	s	0	. . .	. .	0	0	. . . .	. .	. . .	. . .	. .			. .	
21	0	. . .	. .	0	0	1.954	s	0	. . .	. .	0	0	. . . .	. . .	3	1	4	HA	RB	0.2	45
22	0	. . .	. .	0	0	. . . . .	. . .	1	. . .	. .	1*	1*	. . . .	. . .	3	3	4	HV	RV	0.4	50
23	0	. . .	. .	0	0	. . . . .	. . .	0	. . .	. .	1	3	. . . .	. . .	9	0*	10	. . . .		. . .	. .
24	0	. . .	. .	1	3	. . . . .	. . .	0	. . .	. .	1	2	1.931	u	9	0	10	. . . .			. .
25	0	. . .	. .	1	2	1.947	s	0	. . .	. .	0	0	1.955	f	0	0	7*	. . . .			. .
26	0	. . .	. .	0	0	1.950	s	0	. . .	. .	0	0	1.963	f	9	0	10	. . . .	. . . .	. . .	
27	0	. . .	. .	0	0	1.961	u	1	. . .	. .	1^f	2^f	1.959	u	9	0	10	. . . .	. . . .	. . .	
28	0	. . .	. .	2^e	4^e	. . . . .	. . .	1	. . .	. .	0	0	1.949	s	9	0	10*	. . . .			
29	0	. .	. .	1^f	4^f	. . . . .	. . .	1	. . .	. .	0	0	. . . .	. .	1	1	9	H I	. . . .	0.2	50
30	1	i	3 20	0	0	. . . . .	. . .	1	. . .	. .	0*	0*	. . . .	. . .	1	1	8	HV	. . . .	0.2	25
31	1	i	. .	0*	0*	1.965	f	1	. . .	. .	0	0	. . . .	. . .	1*	1*	9*	HV*	. . . .	0.4*	40*
Mean	0.2		.	1.1	1.5	1.959	. . .	0.4	. .	. .	0.8	2.2	1.954	.	4.9	0.6	8	.			. . .

The present values of the solar constant published in these tables are from Table Mountain, California, and have not so great weight as those formerly furnished from Montezuma. The columns headed solar constant show (1) the value in calories of the solar constant, and (2) by letters *s*, *f*, and *u* whether the determination was satisfactory, fair, or unsatisfactory, respectively.

Under the general heading of aurora in the Table, the first column gives the character of the day: 0 indicates no aurora; 1, faint; 3, moderate; 5, strong; 7, brilliant; and 9, no observation or no observations possible on account of cloudiness. The second column gives the number of hours during which aurora was present. The third column indicates the amount of sky covered by cloud on a scale of 0-10, where 0 means cloudless, and 10 completely overcast.

Columns four and five describe by letters the form of the aurora, column four indicating forms without ray structure and column five, forms with ray structure. The letters employed are the same as those

of cosmic data, July to September, 1934

August — Aurora Position	August — G.M.T. greatest distur. (h)	Magnetism Char.	Type	G.M.T. begin. distur. h	m	Sun-spot Groups	No.	Solar constant Value (cal)	Char.	Sept. Aurora Char.	Duration (hrs)	Cloudiness	Form With-out rays	With rays	Area covered	Av. altitude (°)	Position	G.M.T. greatest distur. (h)	Date
		1				0	0			3*	4*	3*	HV*	RV*	0.6*	50*	NW-N-E*	10*	1
		1				0	0	1.949	u	9	1	10*							2
		1				0	0	1.960	f	1	1	9	HA	....*	0.2	85	NW-N-NE	8	3
		0				0	0	1.945	u	1	1	9	HA		0.2	80	NW-N-E	11	4
		0				0	0			1	1	9	HA		0.2	30	NW-N-NE	9	5
		0				0	0	1.950	f	3	3	6	HV	....*	0.2*	40	NW-N-NE	9	6
		1				0	0	1.949	s	9	0	10							7
		1				0	0	1.946	f	3	4	1	HV	RV	0.6	50	NW-N-E	11	8
		0				0	0	1.935	f	1	3	1	HV	RA	0.4	35	NW-N-E	9	9
		0				0	0	1.965	u	1	1	4	HV		0.4	35	W-N-E	9	10
		0				0	0	1.950	s	1	1	6	HA		0.2	42	NW-N-E	9	11
		1				1	2	1.953	s	5	6	0	HV	RV	0.4	50	NW-N-E	8	12
		1				1	1	1.952	f	1	3	0	HV	RA	0.4	35	NW-N-E	12	13
		0				2	6	1.946	f	3	6	1	HV	RA	0.4	35	NW-N-E	8	14
		0				2	4			1	5	0	HA	RA	0.4	30	NW-N-E	10	15
		0				1	2	1.948	u	3	6	0	HV	RA	0.8	60	NW-N-E	10	16
		1				0	0			3	6	0	HV	RV	0.6	80	W-N-E	10	17
		0				0	0	1.940	u	3	6	0	HV		0.6	30	NW-N-E	8	18
		0				0	0	1.964	f	1	2	4	HA		0.2	25	N-NE-E	9	19
		0				0	0	1.951	s	1	2	2	HV		0.2	20	NW-N-E	8	20
N-NE-E	9	0				0	0	1.950	f	1	1	1	DS	RV	0.2	30	NW-N-E	12	21
NW-NE-E*	11	1				0*	0*	1.969	u	9	0	10							22
		0						1.962	u	9	0	10							23
		1						1.959	f	3	3	5	HV	RV	0.6	75	W-N-E	10	24
		1				0	0	1.959	f	5	7	2	HV	RV	0.6	90	W-N-SE	7	25
		1				0	0	1.953	s	9	0	10							26
		1				0	0	1.956	s	0	0	8							27
		0				2*	4*	1.953	s	1	2	4	HV		0.2	50	NW-N-NE	11	28
N-NE-E	9	0				4*	9*	1.955	s	1	1	3	HV		0.2	40	NW-N-E	13	29
NW-N-NE	8	0				3	7	1.952	s	1	4	5	HV	RV	0.4	30	W-N-E	11	30
NW-N-NE*	9*																		31
	9	0.4				0.6	1.2	1.953		3.1	2.7	4							10	Mean

iOne new cycle, six old cycle.　　jTwo new cycle, seven old cycle.　　kTwo new cycle, seven old cycle.
lOne new cycle, one old cycle.

used in the Photographic Atlas of Auroral Forms published by the International Union of Geodesy and Geophysics, Oslo, 1930, so far as it was possible to use those letters. For forms without ray structure *HA* indicates homogeneous quiet arcs; *HB*, homogeneous bands; *PA*, pulsating arcs; *DS*, diffuse luminous surfaces; *PS*, pulsating surfaces; *G*, feeble glow; *HV*, varied forms; *HF*, flaming aurora; and *HVF*, varied forms with flaming. For forms with ray structure *RA* indicates arcs; *RB*, bands; *D*, draperies; *R*, rays; *C*, corona; *RV*, varied forms; *RF*, flaming aurora; and *RVF*, varied forms with flaming.

Column six gives the maximum area of sky covered in tenths of the whole sky, column seven the average altitude in degrees, and column eight the general position of the aurora, being reckoned for included positions in a clockwise direction with Z representing zenith and A the whole sky. The final column gives the Greenwich mean hour of the observed greatest display in the preceding 24 hours of the Greenwich day.

The table of Kennelly-Heaviside Layer heights is self-explanatory.

Beginning January 1, 1934, the magnetic information for the *URSI*-gram is for Cheltenham, Maryland, instead of Tucson, Arizona. In addition to this change in observatory, the data cover the 24 hours ending 8 A. M., 75° west meridian mean time, instead of the 24 hours ending at 7 A. M., 105° west meridian mean tme.

All indicated revisions of auroral data as originally broadcast are in accordance with written report to the Department from Professor Veryl R. Fuller, Alaska Agricultural College and School of Mines, Fairbanks, Alaska.

C. C. Ennis

Department of Terrestrial Magnetism,
  Carnegie Institution of Washington,
    Washington, D. C.

PRINCIPAL MAGNETIC STORMS

SITKA MAGNETIC OBSERVATORY

JULY TO SEPTEMBER, 1934[1]

(Latitude 57° 03'.0 N., longitude 135° 20'.1 or 9ʰ 01ᵐ.3 W. of Gr.)

July 30.—This storm began sharply at 3ʰ 19ᵐ, G. M. T., in all three elements, although the initial amplitudes were not large. At first the two intensity-components increased, while the east declination decreased. This trend was reversed at about 7ʰ. From then on the fluctuations became more violent, reaching their largest amplitudes at about 12ʰ, when the horizontal intensity had dropped to 14527 gammas, more than 900 gammas below normal. The maximum had come at about 6ʰ 51ᵐ, when its value was 15826 gammas, giving a range of 1299 gammas. Ranges of the other elements were: Declination, 131'; vertical intensity, 735 gammas. The storm ended at about 16ʰ.

There were no other storms of importance during this period.

JOHN HERSHBERGER, *Observer-in-Charge*

CHELTENHAM MAGNETIC OBSERVATORY

JULY TO SEPTEMBER, 1934[1]

(Latitude 38° 44'.0 N., longitude 75° 50.'5 or 5ʰ 07ᵐ.4 W. of Gr.)

There were no storms of importance recorded during the third quarter of 1934.

EOLINE R. HAND, *Officer-in-Charge*

HUANCAYO MAGNETIC OBSERVATORY

JULY TO SEPTEMBER, 1934

(Latitude 12° 02'.7 S.: longitude 75° 20'.4 or 5ʰ 01ᵐ.4 W. of Gr.)

Greenwich mean time						Range		
Beginning			Ending			Decl'n	Hor. int.	Ver. int.
1934	h	m	d	h	m	'	γ	γ
July 3	10	32	3	19	..	7	126	39
July 30	3	18	30	21	..	5	157	49

July 3—A minor disturbance of short duration beginning with a marked sudden commencement was recorded at 10ʰ 32ᵐ, G. M. T., when the *H*-trace moved suddenly upwards, increasing 42 gammas in 5 minutes. At the same time *D* increased 0'.3 and *Z* increased 5 gammas. Oscillations of small amplitude superimposed on slow larger movements then set in and continued until 19ʰ, G. M. T., when the disturbance ceased rather abruptly, though slightly disturbed conditions prevailed for the next few days.

July 30—This moderate disturbance began with a sudden commencement in all three elements at 3ʰ 18ᵐ, G. M. T. The sudden increases in the three elements amounted to 0'.4 in *D*, 51 gammas in *H*, and 7 gammas in *Z*. Afterward the horizontal intensity decreased by a series of irregular movements until 7ʰ 10ᵐ when the minimum value of the storm was reached. During the next four hours there was a series of irregular bays followed by a two-hour period of rapid oscillations. The normal trend of the *H*-curve was resumed at 21ʰ. The declination and vertical-intensity traces were but slightly disturbed.

J. E. I. CAIRNS, *Observer-in-Charge* (to August 31)
O. W. TORRESON, *Observer-in-Charge* (after September 1)

Apia Observatory
July to September, 1934
(Latitude 13° 48'.4 S.; longitude 171° 46'.5 or 11ʰ 27ᵐ.1 W. of Gr.)

July 3·—A sudden commencement with a sharp rise of 25 gammas in horizontal intensity took place at 10ʰ 32ᵐ, G. M. T. The trace rose to a maximum of 35080 gammas at 11ʰ 59ᵐ and then fell to a minimum of 35039 at 12ʰ 38ᵐ. It was slightly irregular during the next 36 hours. Declination increased suddenly by 0'.5 towards east and vertical force likewise increased by 5 gammas, the fluctuations of the Godhavn balance being similar to those of the *H*-variometer.

July 30·—The sudden commencement occurred at 3ʰ 18ᵐ, G. M. T., with an increase of 25 gammas in horizontal intensity during an interval of four minutes. The maximum occurred at 3ʰ 39ᵐ and the minimum at 10ʰ 05ᵐ, the range being 168 gammas. Slight irregularities were present during the next few days. Declination decreased gradually from east and vertical force showed a sudden increase of 5 gammas with similar variations in the horizontal force.

J. Wadsworth, *Director*

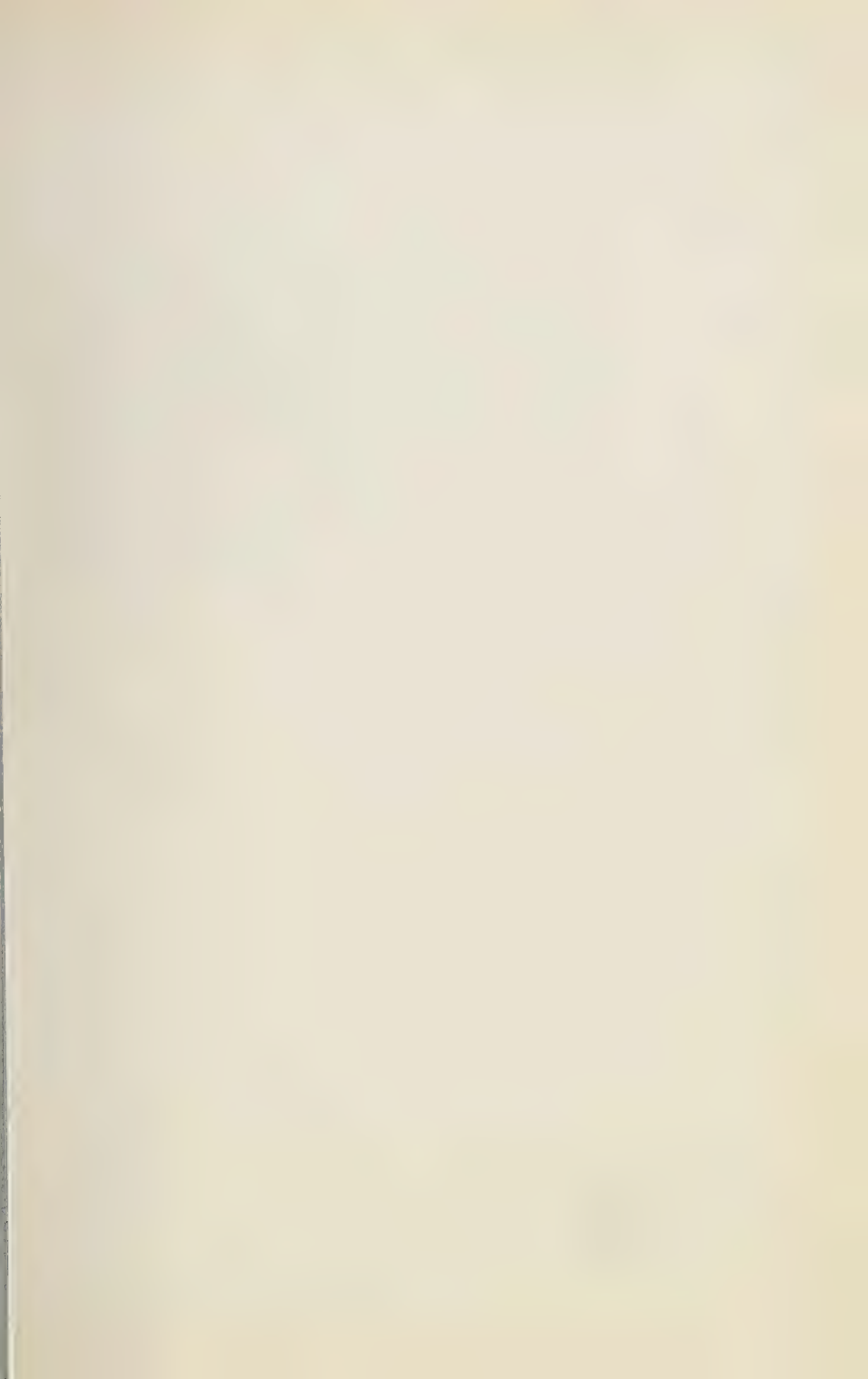## Watheroo Magnetic Observatory
July to September, 1934
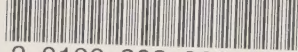#### (Latitude 30° 19'.1 S.; longitude 115° 52'.6 or 7ʰ 43ᵐ.5 E. of Gr.)

Greenwich mean time						Range		
Beginning			Ending			Decl'n	Hor. int.	Ver. int.
1934	h	m	s	d	h	m	'	γ	γ
July 3	10	32	25	3	13	..	6	62	45
July 30	3	18	35	30	22	..	8	165	151

July 3—This small disturbance of comparatively short duration was marked by a sudden commencement in all three elements. The time of the commencement, taken from the trace of the Mitchell vertical-intensity inductometer, was 10ʰ 32ᵐ 25ˢ (±3 seconds), G. M. T. At this time the horizontal intensity increased by 20 gammas in four minutes of time and small decreases were noted in declination and vertical intensity. Small but rapid fluctuations ensued until 13ʰ after which normal conditions were resumed.

July 30·—This disturbance of moderate intensity was of comparatively short duration. The sudden commencement was well marked in all three elements and occurred at 3ʰ 18ᵐ 35ˢ (±3 seconds), G. M. T, the time being taken from the trace of the Mitchell vertical-intensity inductometer. In the horizontal intensity the value increased by 10 gammas and returned to almost its former value, the whole movement occupied only 40 seconds of time; the horizontal intensity thereupon ascended to a maximum increase of 35 gammas, this maximum occurring at 3ʰ 40ᵐ. Afterward the horizontal intensity decreased slowly by a series of irregular movements until a minimum value (about 125 gammas below normal) was reached at 11ʰ 04ᵐ. From this point onward the horizontal intensity increased until normal registration was regained at about 22ʰ. There were no noteworthy features of the declination or vertical-intensity traces. The maximum vertical intensity was reached at 13ʰ 21ᵐ.

W. C. Parkinson, *Observer-in-Charge*

DATE DUE